STEAM BOILERS:

THEIR

DESIGN, CONSTRUCTION, AND MANAGEMENT.

BY

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NEW YORK:

D. VAN NOSTRAND, PUBLISHER,

23 WARREN AND 27 MURRAY STREETS.

1880.

H. J. HEWITT, PRINTER AND ELECTROTYPER, 27 ROSE STREET, NEW YORK.

TO THE

HONORABLE R. W. THOMPSON,

SECRETARY OF U. S. NAVY,

IN RECOGNITION OF HIS EMINENT PUBLIC SERVICES AND PRIVATE WORTH,

THIS BOOK

IS RESPECTFULLY INSCRIBED

BY THE AUTHOR.

PREFACE.

THE author of this work indulges the hope that he has in some degree supplied a long-felt need in this particular branch of engineering and construction.

His thanks are due to Chief Engineer Frederick G. McKean and Passed Assistant Engineer Charles R. Roelker, United States Navy, for the cordial assistance given him in its preparation; especially to Engineer Roelker for the great care and excellent judgment exercised in arranging and classifying the various formulæ and data used. He would also tender to Chief Engineer B. F. Isherwood, United States Navy, his thanks for valuable suggestions.

In quoting authorities he has endeavored to give due credit where it belonged, and any omission in this particular is to be attributed to unintentional oversight.

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STEAM BOILERS:

THEIR

DESIGN, CONSTRUCTION, AND MANAGEMENT.

CHAPTER I.

INTRODUCTORY REMARKS.

In the early days of the steam-engine, when the working pressure was low, boilers were made of various materials, many of which were soon discarded; cast-iron, and, in particular instances, even granite and wood, were used.

Later, copper became a favorite material for the construction of boilers, and it remained in use in the United States Navy up to 1858. Its discontinuance was caused by its greater first cost, greater weight in the vessel, and greater difficulty of keeping its seams tight, than in the case of plate-iron, but principally the former. It went out of use everywhere long before the employment of steam-pressures too high for its tensile strength; and, for a long period before its total disappearance, it was used in national navies only, on account of its durability, as it exceeded iron threefold in that respect. The greater cheapness of plate-iron superseded it at once in merchant-steamers as soon as the manufacture of that material was sufficiently perfected. A serious objection to copper for steamers, independently of its greater cost, was that boilers constructed of it had a much greater weight than plate-iron boilers of the same dimensions and strength, because of its greater specific gravity, and of its greater cross-sections of metal required by its less tensile strength to support equal tensile strains.

The difficulty in keeping the joints of copper boilers water-tight was an important practical defect, and arose from the fact that the oxide resulting from copper corrosion has scarcely any adhesion to the metal, so that a leak once commenced continually increased by the washing away of the material around it; whereas the oxide resulting from the corrosion of iron boilers has so strong an adhesion to its metal, and is so

bulky in proportion to its metallic constituent, that small leaks are soon stopped by the very corrosion they produce.

The introduction of the compound engine, necessitating high boiler-pressures for the development of its best economy, at once doubled and trebled the steam-pressures previously employed with simple engines supplied with steam from boilers having rectangular shells, compelling thereby the abandonment of that form and the substitution of cylindrical shells. With steam-pressures still increasing, and with the necessity continually pressing for lighter weights of machinery with increased powers for steamers, the joints of cylindrical shells have been changed from single to double and to treble riveted; and the tendency now is to the substitution of steel as a material in place of plate-iron, of the welded joint with covering-plates in place of riveted joints, and of boilers formed of tubes of small diameters variously arranged.

The essential parts of a steam-boiler are:

1st. The ashpit or chamber lying beneath the grate.

2d. The grate lying between and separating the ashpit from the furnace.

3d. The furnace or chamber lying immediately above the grate.

4th. The flues or tubes, together with their connecting chambers, extending from the furnace to the chimney.

5th. The chimney.

6th. The water-room enclosing the furnace, tubes, flues, and connecting chambers.

7th. The steam-room lying above the water-room.

From the ashpit air is supplied through the grate to the fuel lying upon it, the ash from this fuel falling into the pit. The grate supports the fuel, which is evenly spread over it in such a manner that the air passing through its interstices may be uniformly distributed. The furnace contains the fuel whose constituents are burnt by combination with the oxygen of the air entering through the grate. The portion of the furnace above the fuel serves in part as a combustion-chamber where the uncombined gases of the air and fuel may be brought by mixture into contact while still at a sufficiently high temperature for combustion.

The flues, the tubes, and their connecting chambers, together with the furnace, constitute the heating surface by means of which the heat in the gaseous products of combustion is transferred to the water enveloping those surfaces. The chimney delivers into the atmosphere the gases of combustion after their heat has been extracted to the desired temperature by the heating surfaces. It also causes the "*draught*" by means of which a constant supply of new air is furnished to the fuel, thereby rendering the combustion continuous. The water-room contains the water to be vaporized,

and the steam-room contains the steam after it has been evaporated. The first may be only of sufficient capacity to form barely an envelope to the heating surfaces; but the latter must be at least large enough to prevent the pressure of the steam in it from sensibly varying with the intermittent draughts of the steam-cylinder.

It is quite evident that an ingenious engineer could form of the elementary parts of a boiler just enumerated an almost infinite number of combinations; those which have actually been devised and executed are so numerous that a large space would be required to describe them, and their description for the most part would be as useless as tedious. As they can be found extensively illustrated in Patent-Office reports and in existing engineering literature, the present essay will be restricted to a consideration of only such as have been found by long experience to meet the requirements of practice, and chiefly of those best adapted for use on board of war and ocean merchant steamers.

The general conditions which determine the peculiar features of marine boilers are the following: the weight of, and the space occupied by, the boilers in a vessel are necessarily limited; economy in fuel is required not only on account of its cost, but on account of its weight and the space occupied by it; the height of the chimney is limited, and the location of the boilers in the hold of the vessel interferes with the draught; the great liability of marine boilers to the evil effects of scale and corrosion makes it imperative that their interior should be easily accessible for cleaning and repairs; the rolling and pitching of the vessel strains the boilers and keeps their water in constant motion; special precautions have to be taken to guard against fire; the boilers have to remain in action often for weeks, day and night, without interruption.

In a man-of-war the boilers must be placed as low as possible, in order to protect them against the chances of penetration by shot; the duty required of them is very unequal: they may lie idle for years; at other times steam may have to be kept up in them for months continuously; they will be required to develop their full power only on exceptional occasions; to be prepared for all emergencies, they must be able to generate steam rapidly, and preserve their efficiency under greatly varying conditions.

CHAPTER II.

COMBUSTION.

1. Elementary Constituents of Fuels.—Chemical combination is always accompanied by the development of heat, and when the latter is sufficiently intense to produce light the combination is called combustion, and the combining substances are called combustibles.

The chief combustible constituents of fuel are carbon and hydrogen, and their chemical combination with the oxygen of the atmosphere is the source of the heat used in steam boilers. Most fuel contains also sulphur and nitrogen, whose combination with oxygen likewise produces heat, but the amount is too insignificant for consideration in a treatise like this.

TABLE I.

Name.	Symbol.	Proportions of elements by weight.	Chemical equivalent by weight.	Proportions of elements by volume.	Chemical Equivalent by volume.	Specific Heat at constant pressure.	Weight of a cubic foot in pounds at 32° and atmospheric pressure.	Volume in cubic feet of one pound at 32° and atmospheric pressure.
Oxygen	O	....	16	....	1	0.218	0.0893	11.204
Nitrogen	N	....	14	....	1	0.244	0.0784	12.753
Hydrogen	H	....	1	....	1	3.405	0.0056	178.83
Carbon	C	....	12	....	..	....	......	......
Sulphur	S	....	32	....	..	....	......	......
Air..................	....	N77+O23	..	N79+O21	..	0.238	0.0807	12.387
Water	H_2O	H2 +O16	18	....	..	1.000	62.425 *	0.016*
Aqueous vapor	....	....	..	H2 +O	2	†0.480	0.0502	19.913
Carbonic oxide	CO	C12 +O16	28	C +O	2	0.245	0.0781	12.820
Carbonic acid	CO_2	C12 +O32	44	C +O2	2	0.217	0.1234	8.101
Olefiant gas	CH_2	C12 +H2	14	C +H2	2	0.369	0.0795	12.58
Marsh gas...........	CH_4	C12 +H4	16	C +H4	2	0.593	0.0447	22.388
Sulphuretted hydrogen.	SH_2	S32 + H2	34	....	2	....	......	......
Sulphurous acid......	SO_2	S32 +O32	64	....	2	0.154	0.1814	5.514
Bisulphuret of carbon.	S_2C	S64 + C12	76	....	2	0.158	0.2137	4.679
Ammonia	NH_3	N14 + H3	17	....	2	....	......	......

* The weight and volume of water are given for the temperature at which it attains its greatest density—viz., 39°.1 Fahr.

† For aqueous vapor in the gaseous state, not saturated vapor.

"Substances combine chemically in certain proportions only. To each substance known in chemistry a certain number can be assigned, called its '*chemical equivalent*,' and having these properties: I. That the proportions by weight in which substances combine chemically can all be expressed by their chemical equivalents, or by simple multiples of their chemical equivalents; II. That the chemical equivalent of a compound is the sum of the chemical equivalents of its constituents." (*Rankine.*)

The elementary substances entering into the composition of the atmospheric air, and of the combustible portion of different fuels, are: oxygen, nitrogen, hydrogen, carbon, and sulphur. The preceding table contains the principal chemical and physical properties of these substances and of the most important compounds formed by them, as found in different fuels and in the products resulting from their combustion.

The chemical equivalents are given in round numbers, omitting fractions too small to be of consequence in calculations connected with the subject of the present treatise.

It must be borne in mind that atmospheric air is not a chemical compound, but a mechanical mixture of nitrogen and oxygen.

2. Temperature of Ignition.—At a temperature of about 750° Fahr. solid bodies become luminous, emitting a dull red light; the intensity of the light increases with the temperature till a dazzling white heat is attained. Gases become luminous only during the process of combustion, forming what is called flame. The flame of gases has little brilliancy, unless intensified by the presence of small particles of incandescent solid matter. Combustion cannot be maintained at a temperature lower than 800 degrees.

3. Combustion of the Constituents of Fuels.—The action, during combustion in the furnace, of the principal constituents of the various kinds of fuel commonly used is described by Rankine as follows: (I.) *Fixed or free carbon*, which is left in the form of charcoal or coke after the volatile ingredients of the fuel have passed off by distillation. It burns without flame; when raised to a state of incandescence, each equivalent by weight of carbon combines with two equivalents of oxygen, forming an invisible gas called *carbonic acid*. If the carbonic acid gas remains in contact with incandescent carbon it dissolves an additional equivalent of carbon, forming with it a compound called *carbonic oxide*, which contains only one equivalent of oxygen for each equivalent of carbon. When, at a sufficiently high temperature, the carbonic oxide comes in contact with oxygen, it absorbs a sufficient quantity to form carbonic acid, burning during this process with a blue flame.

(II.) *Hydrocarbons*, such as olefiant gas, pitch, tar, naphtha, etc., all of which must pass into the gaseous state before being burned.

If mixed, on their first issuing from amongst the burning carbon, with a sufficient quantity of air, these inflammable gases are completely burned with a transparent blue flame, producing carbonic acid and steam. When raised to a red heat, or thereabouts, before being mixed with a sufficient quantity of air for perfect combustion, they disengage carbon in fine powder, and pass to the condition partly of marsh gas, and partly of free hydrogen; and the higher the temperature the greater is the proportion of solid carbon thus disengaged.

If the disengaged carbon is cooled below the temperature of ignition before coming in contact with oxygen, it constitutes, while floating in the gas, *smoke*, and, when deposited, *soot*.

But if the disengaged carbon is maintained at the temperature of ignition, and supplied with oxygen sufficient for its combustion, it burns while floating in the inflammable gas, and forms red, yellow, or white flame.

(III.) *Oxygen and hydrogen*, either actually forming water, or existing in combination with the other constituents in the proportions which form water. The presence of water, or the constituents forming it, in fuel promotes the formation of smoke or of the carbonaceous flame, as the case may be; probably by mechanically sweeping along fine particles of carbon.

The absorption of the heat required for the vaporization of the water contained in the fuel, or produced by its combustion, may reduce the temperature of the products of combustion below the ignition-point of carbon, but not below the dissociation-point of the hydrocarbons of great molecular condensation.

(IV.) *Nitrogen*, either free or in combination with other constituents. This substance is nearly inert, and the bulk of it passes off uncombined.

(V.) *The sulphur* of the sulphurets of iron and of copper contained in many coals forms sulphuric acid when hydrated, which corrodes the metal of the boiler.

(VI.) *Other mineral compounds* of various kinds form the *ash* left after the complete combustion of the fuel; and also the *clinker*, or glassy material produced by fusion of the ash.

4. Total Heat of Combustion.—Carbon and hydrogen are the only constituents of fuel, the combustion of which is of practical value for the generation of heat in the steam boiler. The following table contains the quantities of heat developed by the combustion of one pound of these elements and of their compounds, as determined by the careful experiments of Favre and Silbermann, together with the weight of oxygen necessary for their combustion, and likewise the weight of air required to furnish this amount of oxygen.

The thermal unit, commonly employed by scientists who use British measures, is the quantity of heat required to raise the temperature of one pound avoirdupois of pure water of 39°.1 one degree on Fahrenheit's scale, the barometer standing at 29.922 inches of mercury at 32° Fahrenheit, at the level of the sea, in latitude 45 degrees.

TABLE II.

Combustible.	Pounds of oxygen per lb. of combustible.	Pounds of air per lb. of combustible.	Total heat in thermal units.	Pounds of water that can be evaporated under atmospheric pressure from 212°.
Hydrogen	8.	34.8	62,032	64.2
Carbon (combustion producing carbonic acid)	2.666	11.6	14,500	15.0
Carbon (combustion producing carbonic oxide)	1.333	5.8	4,400	4.55
Carbonic oxide	0.571	2.483	4,329	4.48
Marsh gas	4.	17.4	23,883	24.3
Olefiant gas	3.43	14.9	21,344	22.1

The production of 3.66 pounds of carbonic acid gas by the complete combustion of one pound of carbon is accompanied by a development of heat more than three times greater than the amount of heat generated by the incomplete combustion of the same weight of carbon, producing 2.33 pounds of carbonic oxide. When, however, these 2.33 pounds of carbonic oxide combine with a sufficient quantity of oxygen to form 3.66 pounds of carbonic acid, 10,100 additional units of heat are generated, so that the total amount of heat produced by this twofold process is equal to the heat produced by the conversion of one pound of carbon into carbonic acid.

The total heat of combustion of a compound of hydrogen and carbon (with the exception of marsh gas) is generally assumed to be nearly the sum of the quantities of heat which the hydrogen and carbon contained in it would produce separately by their combustion.

In many such compounds, however, the quantity of heat is greater than this sum, depending on the degree of condensation of the constituents in the molecule. In the case of perfectly dry wood, in which oxygen exists in addition to carbon and hydrogen, it is only the excess of the latter over the oxygen constituent in the proportion necessary to form water which produces a heating effect; but this fact cannot be extended inferentially to other compounds of carbon, hydrogen, and oxygen—such, for example, as coal—for in their cases their heating powers have been experimentally shown to even exceed that of the sum of their full constituents. The heating power of any hydro-

carbon can only be known by direct experiment upon it, but a sufficiently close approximation for practice can be made by employing the old law of Dulong based on experiments with wood. This law is that, when hydrogen and oxygen exist in a compound, only the surplus of hydrogen, above the amount required for combination with the oxygen present in the fuel, will be effective in raising the total heat of combustion.

In computing the total heat of combustion of a compound it is convenient to substitute for the hydrogen a quantity of carbon which would give the same quantity of heat; this is done by multiplying the weight of hydrogen by $\left(\frac{62,032}{14,500}\right)=4.28$.

On these principles are based the following general formulæ for computing the *theoretical* calorific power of any compound of which the principal constituents are carbon, hydrogen, and oxygen.

C, H, and O represent the fractions of one pound of the compound, which are, respectively, carbon, hydrogen, and oxygen; U is the total heat of combustion of the compound, expressed in British thermal units; and E denotes the theoretical vaporific power of one pound of the compound, expressed in pounds of water vaporized from 212° under atmospheric pressure; then

$$U=14,500\left\{C+4.28\left(H-\frac{O}{8}\right)\right\}. \text{[I.]}$$

$$E=\frac{U}{966.1}=15\left\{C+4.28\left(H-\frac{O}{8}\right)\right\}. \text{[II.]}$$

The *actual* calorific power of coals cannot be determined with exactness by the above method, for the following reasons:

1st. Different forms of pure carbon differ considerably in calorific power. According to Favre and Silbermann, wood charcoal has the highest calorific power, equal to 14,544 units, and diamond has the lowest, equal to 13,986 units.

2d. The quantity of heat which becomes latent in the decomposition of the various chemical compounds entering into the composition of coals before combustion takes place, varies with the nature of these compounds. The recent experiments of Scheurer-Kestner and C. Meunier developed in many instances great discrepancies between the actual and the calculated calorific powers of coals. In the case of two coals, the one from Ronchamp and the other from Creusot, which contained almost precisely the same proportions of carbon, hydrogen, and oxygen, the calorific powers, instead of being, in accordance with calculation, identical, were 16,411 and 17,320 respectively. The difference between the real and calculated calorific powers amounted in some instances to as much as 15 per cent.

The quantity of heat that may be generated by the complete combustion of a fuel is not the measure of its vaporific power in a steam boiler; the latter depends in a great measure on the temperature of combustion, and the completeness of the combustion of the fuel in the boiler, and can be determined only by experiment under conditions of actual practice (see Tables V., VI., and VI.*a*). The utilization of the large quantity of heat generated by the combustion of hydrogen presents great practical difficulties, and Johnson's experiments on the vaporific power of American and English coals, made in 1842–43, established the fact that, when the weight of fixed carbon is less than four times the weight of the volatile combustible matter in a coal, its vaporific power in a steam boiler decreases perceptibly.

5. Fuel as a Source of Power.—By multiplying the units of heat representing the calorific power of a fuel by "*Joule's equivalent*" we find the amount of energy stored up in the fuel and set free by its combustion.

Dr. Joule, of Manchester, found, by carefully-conducted experiments, the result of which he finally communicated to the Royal Society in 1849, that each British unit of heat was produced by the expenditure of 772.69 foot-pounds of work. Other observers who have since tried to determine the mechanical equivalent of heat by various methods have obtained results differing more or less from that of Joule's experiments. The mean of sixteen of the most accurate of these determinations gives 786 as the value of the mechanical equivalent of heat. At a meeting of the Royal Society, held January 24, 1878, Joule read a paper in which he gives an account of the experiments he had recently made, with a view to increase the accuracy of the results given in his former paper. The result he has now arrived at from the thermal effects of the friction of water is that, taking the unit of heat as that which can raise a pound of water, weighed in vacuo, from 60° to 61° Fahr. of the mercurial thermometer, its mechanical equivalent reduced to the sea-level, at the latitude of Greenwich, is 772.55 foot-pounds.

For calculations the value of "*Joule's equivalent*" is generally taken as 772, in round numbers.

A recent and careful determination of the mechanical equivalent of heat was made by a Commission of the French Academy, which found that 789¼ foot-pounds of work were equivalent to the heat required to raise the temperature of one pound of water at 32° to 33° under the standard atmospheric pressure. Joule's determination, however, is still generally employed in scientific works.

Taking 14,000 units of heat as representing the average calorific power of good coal, we find that the energy developed by the combustion of one pound of such coal is equal to 14,000 × 772, or 10,808,000 foot-pounds.

6. Air required for Combustion.—To ensure the perfect combustion of a fuel it is necessary—

First, to maintain the combustible matter at such a temperature as is required for its chemical combination with the oxygen of the air.

Secondly, the quantity of air admitted to the furnace must contain a sufficient amount of oxygen. If C, H, and O represent the same quantities as in equation [I.], and A represents the number of pounds of air containing the quantity of oxygen required for the complete combustion of one pound of combustible, then

$$A = 11.6\,C + 34.8\left(H - \frac{O}{8}\right). \text{[III.]}$$

For all practical purposes it is sufficiently accurate to assume the quantity of air chemically required for every kind of coal as 12 pounds per pound of coal.

Thirdly, the air must be thoroughly mixed and brought into actual contact with each particle of the incandescent solid and gaseous matter. In the furnace of a steam boiler this is effected in two ways, viz.: *First*, by admitting the air partly below the fuel, through the evenly-distributed interstices of the grate, and partly, in the shape of numerous small jets, above the solid fuel among the evolved gases in the furnace; and, *secondly*, by admitting a quantity of air in excess of the theoretical quantity required by formula [III]. The amount of this excess varies with different coals and with the manner of introducing the air; but numerous experiments have proved that in ordinary boiler-furnaces, where the draught is produced by means of a chimney, the total weight of air admitted should be, on an average, twice the amount theoretically required for the oxidation of the fuel, or 24 pounds per pound of coal burned; when, however, the draught is produced by artificial means, either by a steam-jet or by a fan-blower, one and a half times the theoretical amount, or 18 pounds per pound of coal, appear to be sufficient.

While an admission of air in excess of the amount actually required for the complete oxidation of the fuel always entails a loss of heat, since the temperature of the uncombined air has to be raised at the expense of the heat of combustion, the loss of heat in consequence of incomplete combustion is generally far greater.

7. Temperature of Combustion.—The elevation of the temperature of the products of combustion, above the temperature at which the air and the fuel are supplied to the furnace, which would be obtained if the combustion was complete, and the whole heat of combustion was spent in raising the temperature of the products of combustion, is called the theoretical calorific intensity of the fuel, and is computed by dividing the total heat of combustion of one pound of fuel by the sum of the products of the weight

and specific heat of the several products of combustion, under constant pressure. When steam is present among the products of combustion, resulting either from the combustion of hydrogen or from water mechanically combined with the fuel, the product of its weight and latent heat must be deducted from the total heat of combustion in the first place. The specific heat of various products of combustion has been given in Table I.; that of ashes is probably about 0.200.

The latent heat of steam at ordinary atmospheric pressure is 966°.1.

TABLE III.

CONTAINING THE THEORETICAL TEMPERATURES PRODUCED BY THE PERFECT COMBUSTION OF VARIOUS SUBSTANCES.

Name of substance.	Pure oxygen supplied sufficient for complete combustion.	Atmospheric air supplied.		
		Sufficient for complete oxidation.	One and a half times the quantity necessary for complete oxidation.	Twice the quantity necessary for complete oxidation.
Hydrogen	12,346°	4,911°	3,556°	2,787°
Carbon	18,257°	4,866°	3 326°	2,526°
Carbonic oxide	12,695°	5,358°	3,921°	3,094°
Olefiant gas	15,475°	4,897°	3,420°	2,627°

Experiments on the combustion of hydrogen and carbonic oxide by Bunsen indicate that the temperature of combustion cannot exceed a certain limit, owing to the phenomenon of "*dissociation*"—that is to say, when the temperature of combustion reaches this limit the elementary bodies no longer combine. When, for instance, hydrogen is burnt in presence of the exact quantity of oxygen necessary for complete combustion, the heat produced by the combustion of a part of the hydrogen is sufficient to raise the temperature of the mixture to such an extent that no further union of the elements can take place. As soon as the temperature begins to fall fresh quantities of hydrogen are burnt, and this process continues until the whole is consumed.

Under the conditions obtaining in the furnace of a steam boiler the temperature of the products of combustion are necessarily always much lower than the preceding table indicates, owing to the more or less incomplete oxidation of the gases, the presence of incombustible matter and of moisture in the fuel and in the air, and the cooling by radiation and conduction. Ledieu states that, under conditions of ordinary practice, the temperature of the gases in the furnace of a marine boiler will hardly exceed 1500°, with a combustion of about 19 pounds of semi-bituminous coal per square foot of grate per hour.

8. Volume of Products of Combustion.—An inspection of Table I. will show that, at equal temperatures, the volume of carbonic acid gas is the same as that of the oxygen entering into its composition; but that the volume of steam is double the volume of oxygen required for the combustion of the hydrogen entering into its composition. Since, in the coals used in marine boilers, hydrogen bears only a small proportion to the whole weight, the volume of the gaseous products of combustion may be treated as practically equal to that of the air supplied to the furnace. The volume of air at 32° may be taken, in round numbers, as 12½ cubic feet for each pound of air. Neglecting the variations in density due to the slight deviations of the pressure of the furnace-gases from the mean atmospheric pressure, as of trifling importance in calculations for practical purposes, the volume of the furnace-gases at any temperature may be calculated by the formula:

$$\frac{V}{V_0} = \frac{T + 461^\circ.2}{493^\circ.2} \quad \text{[IV.]},$$

which expresses the general law "that *the volumes of gases vary directly as their absolute temperatures.*" V and V_0 represent the volume of the gas in question at the temperatures T° and 32° respectively.

The following table, given by Rankine, is based on the foregoing assumptions:

TABLE IV.

Temperature in degrees Fahrenheit.	Volume of gases in cubic feet, per pound of fuel. Supply of air,		
	12 pounds per pound of fuel.	18 pounds per pound of fuel.	24 pounds per pound of fuel.
2500	906	1359	1812
1832	697	1046	1395
1472	588	882	1176
1112	479	718	957
752	369	553	738
572	314	471	628
392	259	389	519
212	205	307	409
104	172	258	344
68	161	241	322
32	150	225	300

9. Rate of Combustion.—The rate of combustion in a furnace is measured by the number of pounds of fuel burned on a square foot of grate per hour. The weight of fuel which can be burned depends on the quantity of air which can be made to pass through the furnace and part with its oxygen to the combustible matter. In practice,

with natural chimney draught, the rates of combustion vary from 7 to 16 pounds for anthracite coals, and from 12 to 27 pounds for bituminous coals, in different types of marine boilers. With artificial draught, produced by a steam-blast or fan-blowers, the rate of combustion may be raised to 120 pounds of coke in certain types of boilers.

The high rate of combustion which can be attained with bituminous coals is owing to the fact that these coals, on being heated in the furnace, part readily with their hydrocarbons in the form of gas, the solid portion of the coal being either left behind as a spongy, porous mass (*coke*), or showing numerous cracks all over the surfaces which divide the lump into a great number of loosely cohering particles. In this manner the air gets access to the interior of the solid coal and comes in contact with a larger surface. The hard anthracite coals, on the contrary, remain solid during combustion, and the air comes in contact only with their exterior.

10. Draught of Furnaces.—The velocity with which air passes through the grate of a furnace depends on the difference of pressures existing within the furnace and the ashpit, and on the resistance offered by the layer of fuel on the grate. The pressure below the grate is the atmospheric pressure, unless it is either increased by forcing air into the ashpit by means of a fan-blower, or diminished by preventing the free flow of air into the ashpit. The pressure above the grate in the furnace is equal to the atmospheric pressure, less the difference in weight of a vertical column of atmospheric air having a base of a unit of area and a height equal to that of the chimney and of an equal column of hot chimney-gas, plus the pressure required to overcome the various resistances experienced by the gases in their passage from the furnace up the chimney. When by the action of a jet or fan the weight of the column of chimney-gas is partly counterbalanced, the pressure in the furnace is correspondingly diminished.

Péclet expresses all the resistances encountered by the gases in their passage from the ashpit to the top of the chimney in terms of the head corresponding to the velocity of the air flowing to the grate, *per se*.

Calling this head h,

the resistance due to the grate and the bed of fuel Gh,

the resistance due to changes in sectional area and direction of the flues Ch,

and the coefficient of friction of the gases moving over the surfaces of the flues f,

he gets an expression of the following form for the total head H_1 which produces the draught of a boiler, viz.:

$$H_1 = h\left[1 + G + C + \frac{f\,l}{m}\left(\frac{t_1}{t}\right)^2\right] = \frac{v^2}{2g}\left[1 + G + C + \frac{f\,l}{m}\left(\frac{t_1}{t}\right)^2\right] \text{ [V.]},$$

where v is the velocity of the air flowing to the grate in feet per second.

In the expression $\frac{v^2}{2g}\frac{fl}{m}\left(\frac{t_1}{t}\right)^2$, which represents the resistance due to friction,

l is the combined length of the flues and of the chimney in feet ;

m is the "*hydraulic mean depth*" of the flues and chimney—that is to say, the mean of the area of the smoke-passages divided by their perimeter ;

t_1 and t are the absolute temperatures of the chimney-gas and of the external air respectively, and $\frac{t_1}{t}$ represents the increase of volume, and consequently of velocity, due to the increase of temperature of the gases in the flues and chimney over that of the entering air ;

f, the coefficient of friction, has, according to Péclet, the value 0.012 for currents of gas moving over sooty surfaces.

The value of Ch varies according to the arrangement, form, and proportions of the smoke-passages, and consists of the sum of the following resistances, which have to be calculated according to the laws governing the flow of fluids :

1.—On entering the tubes or flues the gases experience a loss of head due to the "*contracted vein.*"

2.—Sudden enlargements of the sectional area of the passages produce a loss of head.

3.—Each change in the direction of a current produces a loss of head ; this loss increases with the angle which the two directions make with each other, and is far greater for sudden sharp bends than for bends with easy curves.

4.—Several currents entering a common channel, and moving either with different velocities or in different directions, produce a loss of head.

The value of G varies with the kind of fuel, the thickness of the bed of fuel on the grate, and the velocity of the air passing through the grate. Péclet estimates that when bituminous coal is burnt at the rate of about 22 pounds per square foot of grate per hour, the resistance of the grate is 8 h, and that this resistance varies as the square of the number of pounds of coal burnt per square foot of grate per hour. Coke offers much less resistance than coal.

In coke-burning locomotives Péclet found the value of G to vary from 5.20 to 6.26, and he gives 7.14 h as the mean value of H_1 in locomotives, viz.: 1.93 h for the resistance of the tubes, and 5.21 h for the resistance of the grate. He remarks, however, that these figures are merely rough approximations which may serve to give an idea of the relative value of the different kinds of resistance.

In marine boilers located in the holds of vessels there is an additional loss of head, due to the work expended in drawing the air through the narrow openings in the deck

to the ashpits. Isherwood states that, owing to this cause, the rate of combustion of horizontal, return fire-tube boilers falls from 24 pounds of anthracite consumed when the boiler stands in an open shed, to 16 pounds of anthracite when the boiler stands in the hold of a vessel, natural chimney-draught being used; and with the vertical water-tube boiler of the Martin type the rate of combustion falls, under like conditions, from 16 pounds to 12½ pounds of anthracite coal.

11. Chimney-draught.—"The head produced by the draught of a chimney is equivalent to the excess of the weight of a vertical column of cool air outside the chimney, and of the same height, above that of a vertical column, of equal base, of the hot gas within the chimney." (*Rankine.*)

The weight in pounds of a cubic foot of air at atmospheric pressure at any temperature is given by the formula: $\frac{493.2}{t} \times 0.0807$ [VI.],

where t is the absolute temperature of the air.

The weight in pounds of a cubic foot of the gas discharged by the chimney is very nearly $\frac{493.2}{t_1}\left(0.0807 + \frac{1}{V_0}\right)$ [VII.],

and varies ordinarily from $0.084 \times \frac{493.2}{t_1}$ to $0.087 \times \frac{493.2}{t_1}$.

In this formula V_0 is the volume at 32° of the air supplied to the furnace per pound of fuel;

t_1 is the absolute temperature of the gas within the chimney.

If H denotes the height of the chimney, the unbalanced pressure producing the flow of air to the grate is equal to

$$H\frac{493.2}{t}(0.0807) - H\frac{493.2}{t_1}\left(0.0807 + \frac{1}{V_0}\right);$$

or in case 300 cubic feet of air are supplied for each pound of fuel burned,

$$H\frac{493.2}{t}(0.0807) - H\frac{493.2}{t_1}(0.084), \quad \text{[VIII.]}$$

$$\text{or } H\left(\frac{39.80124}{t} - \frac{41.4288}{t_1}\right). \quad \text{[VIII}a.\text{]}$$

The head, expressed in feet of the external air, corresponding to this pressure is found by dividing the foregoing expression by the weight of a cubic foot of air:

$$H_1 = H\left(1 - \frac{\frac{493.2}{t_1}(0.084)}{\frac{493.2}{t}(0.0807)}\right) = H\left(1 - 1.0409\frac{t}{t_1}\right); \quad \text{[IX.]}$$

Substituting this value of H_1 in equation [V.], we get the following expression for the velocity with which the air flows to the grate of a furnace:

$$v = \sqrt{2gH\left[\frac{1 - 1.0409\,\frac{t}{t_1}}{1 + G + C + \frac{f\,l}{m}\left(\frac{t_1}{t}\right)^2}\right]} \qquad [\text{X.}]$$

The following conclusions may be drawn from this equation, viz.: Under otherwise equal conditions, the velocity of the air flowing to the grate, and, consequently, the rate of combustion, varies very nearly as the square root of the height of the chimney; strictly speaking, it is slightly less, because the value of l in the denominator increases likewise with the height of the chimney.

With a fixed value of t, or absolute temperature of the external air, the value of the numerator, $\sqrt{1 - 1.0409\,\frac{t}{t_1}}$, increases with the temperature of the chimney, and becomes equal to unity when t_1 is infinite; but this increase is very slow with high temperatures. For example, the temperature of the external air being 50° Fahr., the expression $\sqrt{1 - 1.0409\frac{t}{t_1}}$ becomes equal to

.5486, ——— .7059, ——— .7804, ——— 1.000,

when the temperature of the chimney-gas, in degrees Fahr., is

300° 600° 900° infinity.

Since the resistance due to friction, represented by the expression $\frac{f\,l}{m}\left(\frac{t_1}{t}\right)^2$ in the denominator, increases as the square of the absolute temperature of the hot gases, there must be a certain chimney-temperature for which the value of v becomes a maximum; but this temperature varies with the resistances represented by G and C and with the factor $\frac{f\,l}{m}$.

The value of v is further diminished by the cooling of the chimney-gases by the radiation and conduction of heat from the smoke-pipe. This loss increases likewise with the height of the chimney and the temperature of the escaping gases.

Data are wanting to assign exact values to the various resistances under different conditions, but equation [X.] may be used to find the limit of the influence which a change of conditions can have on the efficiency of a boiler.

The height of the chimneys of marine boilers is limited by practical considerations, and it seldom exceeds 65 feet.

The expenditure of heat to produce an increase in the rate of combustion augments so rapidly after a certain limit has been reached that it is not advantageous to increase the chimney-temperature to the point at which the rate of combustion becomes a maximum. It is generally assumed that the chimney-temperature of marine boilers should not exceed 600° Fahr.

12. Artificial Draught.—"The head produced by a *blast-pipe* is equivalent to that part of the atmospheric pressure which is balanced by means of the impact of the jet of steam against the column of gas in the chimney."

"The work which a fan or other blowing-machine must perform in a given time in blowing air into a furnace so as to produce a given head, is found by multiplying the *pressure* equivalent to that head, in pounds on the square foot $\left[H_1 \frac{493.2}{t} (0.0807)\right]$ into the number of cubic feet of air blown in, taken at the temperature at which it quits the blowing-machine."

If t_2 is the temperature on the absolute scale at which the air leaves the blowing-machine, the *net* or *useful* effect of the machine per second will be

$$w V_0 \frac{t_2}{t} H_1 (0.0807) \quad [\text{XI.}];$$

when w denotes the weight of fuel burned in the furnace *per second*,
and V_0 the volume at 32° of the air supplied per pound of fuel.

"The *gross* power or energy required to drive a blowing-fan is greater than the useful work in a proportion which varies much in different machines and is very uncertain." (*Rankine.*)

13. Efficiency of Furnace.—Under otherwise equal conditions the rate of combustion varies very nearly as the square root of the height of the chimney.

This is true on the supposition that the mean temperatures of the chimney-gases are the same from base to top for the chimneys of different heights, and that the gases receive no frictional resistance from the sides of the chimney, neither of which is practically the case. In practice, when gases of the same temperature enter the base of chimneys of different heights the temperature at the top is different, owing to external refrigeration, etc., being less as the chimney is higher, so that the mean temperature in the higher chimney will be less than in the lower one; and the velocity of the draught of the higher chimney will be less comparably with the velocity of the draught of the lower chimney than it should be according to the law of the square roots of the heights.

Again, as the frictional resistances of the sides of the chimney are as the square of the velocity of the gases, the velocity in a chimney sufficiently high would become uniform, after which no further increase of height would increase the draught.

An increase of the furnace-temperature of a boiler of given proportions causes an increase of the chimney-temperature, and, consequently, of the draught; and, *vice versa*, a diminution of the furnace-temperature, in consequence of an excessive amount of air admitted to the furnace or of incomplete combustion, causes a decrease of the chimney-temperature and of the rate of combustion.

In a boiler of given proportions and dimensions the rate of combustion may be varied by aiding the chimney-draught by a jet or fan-blower, or by impeding it by means of a damper in the chimney or flues; by regulating the flow of air to the grate by means of the ashpit-doors; or by increasing or decreasing the resistance of the grate by varying the depth of the bed of fuel.

The draught can be regulated much more readily by means of dampers placed in the flues or chimney than by closing the ashpit-doors.

When the damper is closed the furnace is kept filled with the gases of combustion, which, by enveloping the fuel, effectually prevent its combustion, notwithstanding their leakage out past the damper accompanied by a corresponding entrance of air, for combustion will not take place with the atmospheric oxygen diluted beyond a certain point. But when the ashpit-door is closed—the damper being open or absent—there is a free escape for the gases of combustion, and all the atmospheric oxygen leaked in is available for combustion. Were damper and ashpit-door *perfectly tight* both would be equally efficacious.

The thickness of the bed of fuel can be varied only between certain limits; for, when the bed is too thin, too large a quantity of air will rush through the grate; when it is too thick, the combustion will be incomplete for want of sufficient air.

The principal causes which reduce the efficiency of the furnace of a boiler, by diminishing the temperature of the products of combustion and the total heat produced by the combustion of fuel, are the following:

I. *The absorption of heat by incombustible solid matter and by moisture contained in the fuel.*—The proportion of incombustible matter in coal varies from $1\frac{1}{2}$ to 26 per cent. In the better classes of English semi-bituminous coal used in marine boilers it forms from 6 to 12 per cent. of the fuel. The average quantity of incombustible matter contained in Pennsylvania anthracite is $16\frac{1}{2}$ per cent.

Although the refuse matter has a high temperature when it is removed from the furnace, the quantity of heat thus lost is small, amounting in the worst cases to barely one

per cent. The incombustible matter produces a more injurious effect, especially when it fuses easily and forms clinker, by preventing the free access of air to the combustible portion of the fuel. The principal lossès due to the presence of incombustible matter are connected with the process of cleaning the fires, and will be referred to later.

The moisture present in fuels not only makes latent a relatively large quantity of heat during evaporation, but prevents often the complete oxidation of the combustible portion of the fuel.

Wood, when newly felled, contains, on an average, 40 per cent. of moisture; after eight or twelve months' ordinary drying in air the proportion of moisture is from 20 to 25 per cent. (*Rankine.*)

Coke, being of a porous texture, readily attracts and retains water from the atmosphere; and sometimes, if it is kept without proper shelter, from 0.15 to 0.20 of its gross weight consists of moisture. (*Rankine.*)

The quantity of moisture absorbed by coal varies with its texture, and with the duration and manner of its exposure to dampness. Hard anthracites absorb only a very small quantity of moisture.

II. *Waste of unburnt combustible matter in the solid state.*—This waste depends on the behavior of the fuel during the process of combustion and on the care and skill of the fireman. Anthracite coal, when suddenly heated, splits into small pieces, and dry bituminous coal is converted during combustion into a loosely cohering mass of small particles, which are liable to fall through the grate when the fire is stirred for the purpose of removing the ashes. In cleaning the fire a small quantity of coal is also unavoidably hauled from the furnace with the refuse. "It is impossible to estimate the greatest amount of this kind of waste which may arise from careless firing; but the amount which is unavoidable with good firing has, in some cases, been ascertained by experiment and found to range from nothing up to about 2½ per cent." (*Rankine.*)

III. *Losses arising from an admission of excessive quantities of air to the furnace.*—By admitting too large a quantity of air to the furnace the temperature of the products of combustion is decreased and their mass and volume are increased; the effect of this is a reduction of the rate of combustion, the loss of a larger quantity of heat present in the escaping chimney-gases, and sometimes, when the furnace temperature is greatly reduced, the incomplete combustion of certain gaseous products of the fuel. Too large a calorimeter, or cross-area of the passages over the bridge-wall or through the flues relatively to the rate of combustion, favors the admission of an excessive quantity of air. The proper proportions of the parts of a boiler will be considered later.

The air should pass in thin, evenly-distributed streamlets through the bed of fuel,

or it should enter the furnace above the grate in the form of numerous fine jets. The admission of air in large masses is always injurious, but is to a certain extent unavoidable with the ordinary methods of firing; when the bed of fuel is too thin or not evenly distributed over the grate, and whenever the door is opened for the purpose of throwing fuel on the grate, or levelling, slicing, and cleaning the fire, large masses of air rush into the furnace.

When the fuel is not evenly distributed over the grate, the air rushes with great violence and in large masses through the places left uncovered or insufficiently covered, causing the phenomenon of "*back-draught.*"

When the combustion is forced by artificial draught the lumps of coal must be smaller and the bed of coal must be thicker than with natural draught, so as to make the interstices between the lumps smaller and the route of the air through the bed of coal more tortuous.

The following is the result of "experiments showing the effect on the economic vaporization of admitting an increased air-supply through the grates to the incandescent coal upon them by carrying thinner fires." "In experiment *A* the fires were 7 inches thick, and in experiment *D* they were less than half that thickness, the grates being kept just covered. The rate of combustion in both experiments was sensibly the same, and very slow, being 6.498 pounds of the combustible portion of anthracite per square foot of grate-surface per hour in experiment *A*, and 6.149 pounds in experiment *D*.

"The economic vaporization in experiment *A* was 11.8976 pounds of water from the temperature of 212° Fahr. and under the atmospheric pressure, per pound of the combustible portion of the anthracite, and in experiment *D* 10.2716 pounds. Hence the admission of the increased air-supply through the grates, due to maintaining a very thin fire upon them, decreased the economic vaporization by the fuel $\left(\frac{11.8976 - 10.2716}{11.8976}\right) 100 = 13.667$ per centum." (*Report of Board of United States Naval Engineers on "The Ashcroft Furnace-doors and Grate-bars," March* 27, 1878.)

The loss resulting from opening the furnace-door is avoided or lessened by using a moving grate, to which the fuel is supplied by mechanical means; or by using vibrating or rocking grate-bars for removing the ash and clinker from the fire. The former have not come into use for marine boilers; examples of the latter will be found in Chapter XIII.

The exact amount of the loss in vaporific efficiency of coal burnt in a boiler-furnace,

due to the opening of the door for the purpose of removing the ash and clinker, may be deduced from the experiments made by the Board of United States Naval Engineers convened to determine the relative value of the Murphy shaking-grate and of the common grate: "The Murphy apparatus kept the fires clean and free of holes, crushed the clinker and removed all the refuse from the furnaces into the ashpits, without opening the furnace-doors for such purposes and without using fire-tools"; and it was found "that the economic gain in fuel due to the Murphy grate was in direct proportion to the per centum of refuse removed through the furnace-door, as appears from the following exhibit":

Kind of coal burnt.	Per centum of the coal consumed on the common grate, removed as refuse through the furnace-door.	Economic gain in fuel by the Murphy grate in per centum of the fuel consumed on the common grate.
Bituminous coal, lumps.....	10.9475	4.1529
Bituminous coal, dust.......	13.4338	5.7417
Anthracite	19.3147	7.2972

"The mean of the three determinations gives for the economic loss in fuel when burned on a common grate 0.3935 per centum of that fuel for every one per centum it contains in refuse removed through the furnace-door." (*Report on the Murphy Grate-bar by a Board of United States Naval Engineers, June* 25, 1878.)

IV. *Waste of unburnt fuel in the gaseous and smoky states.*—The complete combustion of coke, hard anthracite, and coals containing only a small proportion of hydrocarbons presents no difficulty as long as the thickness of the bed of fuel is properly proportioned to the draught, and a small quantity of air enters the furnace in jets through the perforated furnace-door in addition to the quantity passing through the grate.

The combustion of highly bituminous coal presents greater difficulties. Special care has to be taken, in the design of the boiler and in the management of the fire, that the hydrocarbon gases distilled from the coal are thoroughly mixed, at a sufficiently high temperature, with the proper quantity of air. A greater or less quantity of the carbon contained in the hydrocarbon gases remains frequently unburnt, forming soot or smoke; and in extreme cases the fixed carbon contained in the coal is alone completely burnt.

"If smoke is mixed with carbonic-acid gas at a red heat the solid carbonaceous particles are dissolved in the gas and carbonic oxide is produced. This is the mode of

operation of contrivances for destroying smoke by keeping it at a high temperature without providing a sufficient supply of air; and the result is a waste instead of a saving of fuel." (*Rankine.*)

TABLE V.

GENERAL SYNOPTICAL TABLE OF THE CHARACTER AND EFFICIENCY OF AMERICAN COALS, BY W. R. JOHNSON.

1	2	3	4	5	6	7	8	9	10	11	12	13
Designation of coal.	Location of mine.	Specific gravity.	Cubic feet of space required to stow a ton.	Volatile combustible matter in 100 parts.	Fixed carbon in 100 parts.	Earthy matter in 100 parts.	Moisture in fuel in 100 parts.	Ratio of fixed to volatile combustible matter.	Rate of combustion in lbs. of coal per square ft. of grate per hour.	Percentage of waste in ashes and clinker.	Pounds of steam from water at 212° per pound of coal.	Steam from 212° from one lb. of combustible.
Beaver Meadow, Slope No. 3.	Pa.	1.610	40.78	2.38	88.94	7.11	1.57	37.37	6.69	11.96	9.21	10.462
Beaver Meadow, Slope No. 5.	Pa.	1.551	39.86	2.66	91.47	5.15	0.72	34.39	6.27	6.74	9.88	10.592
Forest Improvement........	Pa.	1.477	41.75	3.07	90.75	4.41	1.77	29.56	6.52	6.97	10.06	10.807
Peach Mountain............	Pa.	1.464	41.64	2.96	89.02	6.13	1.89	30.09	6.69	6.97	10.11	10.871
Lehigh....................	Pa.	1.590	40.50	5.28	89.15	5.56	0.01	16.88	6.95	7.22	8.93	9.626
Lackawanna................	Pa.	1.421	45.82	3.91	87.74	6.35	2 00	22.44	6.45	8.93	9.79	10.764
Lykens Valley	Pa.	1.389	46.13	6.88	83.84	9.25	0.03	12.19	6.92	12.24	9.46	10.788
New York and Maryland Mining Company.......	Md.	1.431	41.71	12.31	73.50	12.40	1.79	5.97	6.28	12.71	9.78	11.208
Neff's Cumberland.........	Md.	1.337	41.26	12.67	74.53	10.34	2.46	5.88	7.86	10.96	9.44	10.604
Dauphin and Susquehanna .	Pa.	1.443	44.32	13.82	74.24	11.49	0.45	5.37	6.86	16.36	9.34	11.171
Blossburg	Pa.	1.324	42.22	14.78	73.11	10.77	1.34	4.95	7.77	11.20	9.72	10.956
Lycoming Creek...........	Pa.	1.388	40.45	13.84	71.53	13.96	0.67	5.16	6.33	16.92	8.91	10.724
Cambria County............	Pa.	1.407	41.90	20.52	69.37	9.15	0.96	3.38	6.68	9.75	9.24	10.239
Midlothian (average).......	Va.	1.294	41.45	29.86	53.01	14.74	2.39	1.78	6.68	14.83	8.29	9.741
Pittsburgh................	Pa.	1.252	47.85	36.76	54.93	7.07	1.24	1.49	....	8.25	8.20	8.942
Cannelton.................	Ind.	1.273	47.01	33.99	58.44	4.97	2.60	1.72	11.09	5.12	7.34	7.734
Dry pine wood............	....	....	106.62	....	....	0.307	....	....	15.87	0.307	4.69	4.707

TABLE VI.

GENERAL SYNOPTICAL TABLE OF THE CHARACTER AND EFFICIENCY OF ENGLISH COALS, SHOWING THE RESULTS OF THE INVESTIGATIONS OF DE LA BECHE AND PLAYFAIR.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Locality or name of coal.	Specific gravity.	Cubic feet of space required to stow a ton.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Percentage of coke.	Percentage of fixed carbon.	Ratio of fixed to volatile combustible.	Theoretical evaporative power, in pounds of water of 212° per pound of coal.	Actual number of pounds of water of 212° evaporated per pound of coal.
Welsh Graigola	1.30	37.23	84.87	3.84	0.41	0.45	7.19	3.24	85.5	82.26	6.12	13.563	9.35
" Anthracite (Jones, Aubrey & Co.)	1.375	38.45	91.44	3.46	0.21	0.79	2.58	1.52	92.9	91.38	19.60	14.593	9.46
" Old Castle Fiery Vein	1.289	43.99	87.68	4.89	1.31	0.09	3.39	2.64	79.8	76.16	6.02	14.936	8.94
" Binea Coal	1.304	39.24	88.66	4.63	1.43	0.33	1.03	3.96	88.10	84.14	7.65	15.093	9.94
" Llangenneck	1.312	39.34	85.46	4.20	1.07	0.29	2.43	6.54	83.69	77.15	6.30	14.260	8.86
" Pentrepoth	1.31	38.80	88.72	4.50	0.18	....	3.24	3.36	82.5	79.14	4.73	14.838	8.72
" Pentrefelin	1.358	33.85	85.52	3.72	Trace	0.12	4.55	6.09	85.0	....	5.52	13.787	6.36
" Powel's Duffryn	1.326	42.09	88.26	4.66	1.45	1.77	0.60	3.26	84.3	81.04	5.56	15.092	10.15
" Mynydd Newydd	1.31	39.76	84.71	5.76	1.56	1.21	3.52	3.24	74.8	71.56	2.91	14.904	9.52
" Cwm Frood Rock Vein	1.255	40.52	82.25	5.84	1.11	1.22	3.58	6.00	68.8	62.80	2.08	14.788	8.70
" Cwm Nanty-gros	1.28	40.00	78.36	5.59	1.86	3.01	3.58	5.60	65.6	60.00	1.79	13.932	8.42
" Ponty Pool	1.32	40.216	80.70	5.66	1.35	2.39	4.38	5.52	64.8	59.28	1.73	14.295	7.47
" Ebbw Vale	1.275	42.26	89.78	5.15	2.16	1.02	0.39	1.50	77.5	76.00	3.59	15.635	10.21
" Porthmawr Rock Vein	1.39	42.02	74.70	4.79	1.28	0.91	3.60	14.72	63.1	48.38	1.37	12.811	7.53
Scotch Dalkeith Jewel Seam	1.277	44.98	74.55	5.14	0.10	0.33	15.51	4.37	49.8	45.43	1.24	12.313	7.08
" Dalkeith Coronation Seam	1.316	43.36	76.94	5.20	Trace	0.38	14.37	3.10	53.5	50.40	1.14	12.772	7.71
" Fordel Splint	1.25	40.72	79.58	5.50	1.13	1.46	8.33	4.00	52.03	48.03	1.21	13.817	7.56

TABLE VI*a*.

SHOWING THE RESULTS OF EXPERIMENTS ON VARIOUS COALS OF THE CARBONIFEROUS AND CRETACEOUS PERIODS, MADE BY CHIEF-ENGINEER B. F. ISHERWOOD, U.S.N., AT THE MARE ISLAND NAVY-YARD, CALIFORNIA, IN 1871.

Kind of coal.	Name and location of mine.	Specific gravity.	Cubic feet of space required to stow a ton.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash and clinker.	Hygrometric moisture.	Theoretical evaporation in lbs. of water of 212° F. under atmospheric pressure per lb. of combustible portion of fuel.	Experimental economic vaporization in pounds of water from 212° Fahr. under atmospheric pressure per pound of the combustible portion of the coal.			Relative weights of steam obtained from a cubic foot of the different coals.			Maximum rate of combustion in pounds of combustible per hour per square foot of grate.
												At the maximum rate of combustion.	At the medium rate of combustion.	At the slow rate of combustion.	At the maximum rate of combustion.	At the medium rate of combustion.	At the slow rate of combustion.	
Anthracite........	Scranton, Pa..........	1.453	38.08	78.54	2.52	1.68	0.84	0.42	14.84	1.16	15.637	9.504	9.472	9.413	1.0000	1.0000	1.0000	13.122
Anthracite........	Queen Charlotte Isl'd, British Columbia....	1.508	34.62	55.54	1.78	1.19	0.59	0.30	39.75	0.85	15.609	.....	.....	9.472	......	......	0.7834	......
Anthracitic.......	Wales.................	1.390	39.40	84.18	3.68	2.30	0.92	0.92	6.73	1.27	15.952	9.851	9.681	10.673	1.0972	1.0819	1.2002	13.450
Semi-bituminous .	Cumberland, Md......	1.332	40 25	80.55	4.50	2.70	1.08	1.17	8.25	1.75	16.165	9.896	10.246	10.557	1.0614	1.1026	1.1432	15.693
Brown coal.......	Australia (I.)	1.275	41.39	74.02	4.78	7.47	1.11	0.62	8.07	3.93	14.844	8.560	9.898	9.664	0.8946	1.0379	1.0197	18.133
Brown coal.......	Australia (II.)	1.275	41.39	64.25	4.15	10.00	1.00	0.60	10.00	10.00	12.720	7.966	8.509	8.930	0.8150	0.8735	0.9225	17.266
Brown coal.......	Wahsatch Range, Rocky Mountains.																	18.862
" "	Mount Diablo, California.........																	15.027
" "	Coose Bay, Oregon..	1.320	41.98	50.05	3.85	13.65	0.91	1.54	13.18	16.82	10.114	5.420	6.062	6.907	0.5274	0.5919	0.6786	21.761
" "	Seattle, Puget Sound, W. T......																	26.396
Brown coal	Bellingham Bay, W. T..............	1.350	46.90	49.60	3.39	8.96	0.83	1.22	23.48	12.52	11.554	5.778	6.912	8.006	0.5637	0.6760	0.7886	17.702
Brown coal	Nanaimo, Vancouver Island..............	1.302	43.27	59.68	4.08	10.78	1.00	1.46	12.74	10.26	12.243	6.788	8.432	8.249	0.6441	0.8028	0.7903	16.124
Coke.............	From Nanaimo Coal..	0.868	80.00.	.....	....	....	....	....	13.85	13.00	......	7.988	7.798	7.979	0.4048	0.3922	0.4082	13.600

CHAPTER III.

TRANSMISSION OF HEAT AND EVAPORATION.

1. Laws of Transmission of Heat.—All bodies transfer heat to the surrounding cooler bodies till their temperature becomes equalized.

The quantity of heat transferred from one body to another depends on the difference of their temperatures and their respective specific heat, and, in case the molecular condition of one or both bodies is changed, on their respective latent heat.

The rate at which the transfer takes place between two bodies depends, *first*, on the degree and the difference of their temperatures; *secondly*, on the extent of surface transmitting and receiving heat; *thirdly*, on the nature of the material of the bodies, and on the condition of their surfaces; *fourthly*, on the nature and thickness of the intervening substances.

There are three processes by which heat is transferred, called respectively radiation, conduction, and convection.

Radiation is the exchange of heat by direct rays between bodies not in contact, and takes place at all temperatures and at any distance through space.

These rays produce the phenomena of heat only in bodies which intercept them more or less completely. Gases intercept and emit heat-rays very feebly; most solids and fluids, on the contrary, intercept and emit these rays, which are either wholly absorbed or partly reflected by them. The rate of transmission of heat by radiation between two bodies is increased by making their surfaces dark and rough, and diminished by smoothing and polishing them. In the steam boiler the radiation from the solid incandescent fuel is far greater than from the carbonaceous flame, while the transparent hot gases scarcely radiate any heat at all.

Conduction is the transfer of heat between bodies in contact, and is distinguished as external and internal conduction, accordingly as it takes place between two distinct bodies, or between the parts of one continuous body.

Convection is the diffusion of heat in a fluid mass by means of the circulation and mixture of the particles of that mass. The most rapid convection of heat is effected by means of cloudy vapor, which combines the mobility of a gas with the comparatively

greater conducting power of a liquid. Convection is the only process that can be depended upon for the rapid distribution of heat throughout a mass of water.

The rate of *internal* conduction in a solid body depends, *first*, on the variation of temperature along a line perpendicular to the section through which the heat is transferred, and, *secondly*, on the *coefficient of internal conductivity* of the substance in question. Although this coefficient varies slightly with different temperatures, it may be considered practically as constant for the same substance. Designating the number of thermal units transmitted through a square foot of area per hour by Q,
the temperatures of the two sides of a substance by T and T_1,
the rate of conduction through a plate of the thickness t, in inches, may be expressed by the equation :

$$Q = \frac{T - T_1}{\rho t}. \quad [\text{I.}]$$

where ρ may be called, according to Rankine, *the coefficient of thermal resistance.* The value of this coefficient for various substances is as follows: copper = 0.0018; iron = 0.0043*; zinc = 0.0045; lead = 0.0090; marble and calcareous deposits = 0.0716; brick = 0.1500.

When a plate consists of layers of different substances, its total internal thermal resistance may be found by adding together the resistances of the several layers; in such a case equation [I.] assumes this form: $Q = \frac{T - T_1}{\Sigma \rho t}$. [I*a*.]

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* "Principal Forbes . . . has likewise determined the absolute conductivity of wrought-iron. In his experiments conductivity was expressed in terms of the amount of heat as unity which is required to raise the temperature of one cubic foot of water by one degree centigrade. He expresses the amount of heat reckoned in such units which would traverse in one minute across an area of one square foot a plate of iron one foot thick with the two surfaces maintained at temperatures differing by one degree centigrade. According to these experiments, the conductivity at 0° C. of one of his bars was .01337, while that of another bar was only .00992. This discordance was probably due to a difference in the quality of the iron of the two bars." (*Balfour Stewart*, "*An Elementary Treatise on Heat.*")

The larger result was obtained with a square bar 1¼ ins. thick, the smaller one with a square bar 1 inch thick. In either case the conductivity diminished as the temperature increased. In the larger bar,

	the conductivity at	100° C.	was 24.3	per cent. less than at	0° C.
	"	200° C.	" 13.4	" "	100° C.
	"	275° C.	" 8.6	" "	200° C.
In the smaller bar	"	100° C.	" 15.8	" "	0° C.
	"	200° C.	" 8.5	" "	100° C.
	"	275° C.	" 5.2	" "	200° C.

Professor Tait has given reasons for believing that the thermal conductivity of metals may be inversely proportional to their absolute temperature.

The *rate of external conduction* between a solid body and a fluid may be expressed by dividing the difference of their temperatures by a *coefficient of external resistance*, depending on the nature of the substances, the condition of their surfaces, and also on their temperatures. Designating the value of these coefficients for the two surfaces of a given plate by σ and σ_1, the quantity of heat-units transmitted per square foot of surface per hour, from one fluid to another, through a plate t inches thick, may be expressed by the formula: $Q = \dfrac{T - T_1}{\sigma + \sigma_1 + \rho t}$. [II.]

2. Experiments on the Transmission of Heat by Isherwood.—Careful experiments on the heat-conducting power of different metals were made by Isherwood in 1867 at the Washington Navy-Yard. The metals experimented upon were pure, refined copper, brass consisting of 60 parts of copper and 40 parts of zinc, rolled wrought-iron of the best quality, and ordinary cast-iron which had had several remeltings. Cylindrical pots of these metals, 10 inches in inside diameter and 21¼ inches in inside height, were immersed in a common cylinder, which was well protected by a non-conducting material and supplied with steam of a certain temperature and pressure from a large boiler. The pots were kept filled with water of 212° temperature by a steady supply from separate tanks, and the quantity of this water evaporated by the heat supplied by the steam-bath measured the thermal conductivity of the respective metals; hence, "exactly the same temperature was upon the entire exterior surface of all four pots, while the water inside the pots was vaporized under identical hygrometrical and barometrical conditions of the atmosphere. Each experiment consisted of from 54 to 108 hours, nine hours of each day being devoted to it." Great care was exercised to maintain the temperatures equal throughout each experiment, and all conditions were noted every 15 minutes in a tabular log. "Each series of experiments was exactly repeated on pots of three thicknesses of metal—viz., $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{3}{8}$ inch—with the view of ascertaining whether the vaporizing efficiency of the metals was affected by their thickness.

"With each thickness of metal twenty experiments were made, the temperature of the steam increasing by 5° Fahr. from 220° Fahr. for the first to 320° Fahr. for the last experiment. All the pots were turned and bored to exactly the same dimensions.

"For each experiment there was calculated the number of pounds of water vaporized, from the temperature of 212° Fahr. and under the standard atmospheric pressure of 29.92 inches of mercury, by each pot; and the heat-conducting powers of the metals were considered to be in the ratio of those weights. The following are the general results:

"1ST. All other things equal, the weight of water vaporized in a given time was in the direct ratio of the difference of the temperatures, inside and outside of the pots.

"2D. All other things equal, the weight of water vaporized in a given time was not affected by the thickness of the metal. The rate of vaporization was exactly as great from the $\frac{3}{8}$-inch thick metal as from the $\frac{1}{8}$-inch thick metal.

"3D. The following are the fractions of a pound of water vaporized per hour from each square foot of the interior surface of the pots, from the temperature of 212° Fahr. and under the standard atmospheric pressure of 29.92 inches of mercury, by a difference of temperature of one degree Fahrenheit between the inside and the outside of the pots.

"These are the absolute heat-conducting powers of the metals named"—viz.:

	Thermal conductivity in terms of fractions of a pound of water of 212° vaporized under atmospheric pressure.	Thermal conductivity in terms of heat-units transmitted per hour through one square foot of material by difference of temperature of 1° Fahr.	Relative thermal conductivity.
Copper	0.665365	642.543	1.000000
Brass	0.576610	556.832	0.866607
Wrought-iron	0.386895	373.625	0.581478
Cast-iron	0.326956	315.741	0.491393

3. Experiments on the Transmission of Heat by Péclet.—The results of the foregoing experiments agree pretty closely with those obtained by former investigators, as far as the relative thermal conductivity of these metals is concerned; the absolute values obtained are, however, much smaller than those found by Péclet. The latter's experiments prove that the rate at which fluids transmit heat to, and absorb heat from, solid bodies, depends—other conditions being equal—greatly on the more or less perfect circulation of the fluids, so that each particle of fluid is at once replaced by other particles as soon as it has absorbed or parted with some heat by contact with the solid. On this account Péclet used water instead of steam as the source of heat in his experiments, because, by the condensation of the latter, a film of water is deposited on, and clings tenaciously to, the walls of the experimental vessel; and he produced rapid circulation in the heat-absorbing, as well as in the heating, medium by mechanical means. By observing such precautions Péclet obtained results which are in accordance with the law that the quantity of heat transmitted through a solid body in a unit of time diminishes in the direct ratio of the increase of thickness.

Péclet's experiments on the cooling of vessels when exposed to the air, the circulation of the latter being produced simply by the effect of the transmitted heat, proved

that, when the walls of the experimental vessel were covered by pulverulent deposits, the quantity of heat transmitted in a unit of time was independent of the internal thermal conductivity of the metal and, within the limits of ordinary practice, of the thickness of the walls, but depended greatly on the form of the vessel and increased in a certain ratio with the difference of temperature ; both these latter elements affecting the rapidity of the circulation of the air.

4. Transmission of Heat in a Steam Boiler.—Since in a steam boiler the heating-surfaces become soon covered with deposits of scale, rust, and soot, while the circulation of the hot gases on one side and of the water or steam on the other side is more or less imperfect, the evaporative power of these surfaces may be considered, within the limits of ordinary practice, as independent of the thickness and kind of the metal used, but depending principally on their form and position, on the condition of their surfaces, and on the difference of the temperatures to which the opposite sides are exposed.

Rankine expresses the total thermal resistance of the plates and tubes of a steam boiler by $\frac{a}{T - T_1}$; substituting this expression for the divisor $\sigma + \sigma_1 + \rho t$, equation [II.] assumes the form:

$$Q = \frac{(T - T_1)^2}{a}. \quad \text{[III.]}$$

The numerical value of a lies between 160 and 200. This formula is not intended to give more than a rough approximation ; in fact, the varying conditions obtaining in a steam boiler preclude the possibility of an accurate theoretical determination of its coefficient of thermal resistance.

To ensure the proper circulation of the water to which heat is to be transmitted two conditions must be observed—viz., *first*, the heat must be applied to the bottom of the vessel containing the water, so that the latter, as it becomes lighter by being heated, may ascend, being displaced by a descending column of heavier, colder water ; *secondly*, the heating-surfaces must have such a shape and position as to permit the free escape of the heated water and steam.

As long as the clean surface of a boiler-plate is in contact with solid water the most intense heat of the furnace may be applied to the other side without overheating the plate ; when, on the contrary, a plate is in contact with steam, it will soon assume the temperature of the hot gases to which the other side is exposed. This great heat-absorbing capacity of water is owing to three causes : *first*, its thermal conductivity is greater than that of gases ; *secondly*, its specific heat is more than twice as great as

that of steam; and, *thirdly*, a large quantity of heat becomes latent during evaporation.

5. Efficiency of Heating-surfaces in a Steam Boiler.—The efficiency of a heating-surface may be measured by the ratio borne by the amount of heat transmitted by it to the total amount of heat available for transmission. This efficiency in a steam boiler depends on the following conditions: *first*, the proportion which the extent of the surfaces receiving and transmitting heat bear to the volume of hot gas bounded by them; *secondly*, the difference of temperatures of the hot gas on the one side of the plates, and of the water or steam on the other side; *thirdly*, the time allowed for the transmission of heat; *fourthly*, the nature, condition, and thickness of the plates forming the heating-surfaces; *fifthly*, the position and shape of the plates; *sixthly*, the nature of the heating and heat-absorbing media.

The following interesting experiment on the influence of the position of heating-surfaces on their efficiency is recorded by Tredgold: "Mr. Armstrong found that a cubical metallic box, submerged in water and heated from within, generated steam from its upper surface more than twice as fast per unit of area than it did from the sides when vertical, and that the bottom yielded none at all. These remarkable differences are owing to the difficulty with which steam separates from a vertical surface to give place to fresh charges of water, and to the impossibility of leaving the inverted surface at all. By slightly inclining the box the elevated side much more easily parted with the steam, and the rate of evaporation was increased; while on the depressed side the steam hung so sluggishly as to lead to an overheating of the metal."

In the marine steam boiler the temperature of the gases in the furnace ranges probably between 1,500° and 2,500°; and when these gases enter the chimney their temperature has been reduced to from 450° to 650°.

On the other hand, the temperature of the steam, and consequently of the water, ranges between 250° and 350°, according to the steam-pressure used. Since the water is introduced into the boiler at a much lower temperature, varying ordinarily between 100° and 120°, there would be theoretically a decided gain in the heating efficiency if the water entered the boiler at the point where the hot gases have the lowest temperature. Such an arrangement is, however, rarely made in marine boilers, on account of mechanical difficulties connected with it.

The plates forming the furnace of a marine boiler transmit, relatively, by far the greatest amount of heat to the water; for, in addition to the effect produced by the high temperature of the evolved gases in contact with the sides and the top of the furnace, the radiation of heat from the incandescent solid fuel is of considerable impor-

tance. Péclet states that the quantity of heat radiated from incandescent carbon, freely suspended, is at least one-half of its total heat of combustion. In the furnace, however, only the upper surface of the fuel radiates heat directly to the water-heating surfaces. The rays of heat emitted through the open spaces of the grate are mostly absorbed by the ashes; but this heat, as well as that received by the furnace-door, is to a great extent reabsorbed by the entering air.

In the combustion-chamber or back-connection the temperature of the products of combustion is probably fully as high as in the furnace, since the thorough mixing of the hot gases with the air completes their combustion. The radiation of heat from the carbonaceous flame is likewise frequently of much importance at this part of the boiler.

Isherwood states, as the result of experiments on marine boilers, that of the evaporation of water in well-proportioned tubular boilers about 55 per cent. is due to the furnace and back-connection, while the heating-surface contained in those parts is only about 20 per cent. of the total heating-surface of the boiler.

On leaving the combustion-chamber or back-connection the gases pass generally between or into numerous tubes. By subdividing in this manner the gaseous mass into a great number of streamlets the proportion of heating-surface to volume of gas for a given length is greatly increased, and the absorption of heat takes place rapidly.

When the hot gases pass through horizontal tubes the upper side of them is most effective as a heating-surface, since on the inside it is kept relatively clean of sooty deposits and the hottest gases come in contact with it, while at the same time the steam-bubbles escape most freely from that portion of the tubes. Only such portions of the hot gases as come in actual contact with the heating-surfaces impart their heat to them. In internally-heated horizontal tubes the outer film of the hot gases descends as soon as it has parted with some of its heat; in this manner the temperature of the current is equalized to some extent by convection of heat. Some writers ascribe the smaller efficiency of internally-heated vertical tubes to the fact that the outer film of gases in contact with the metal has no tendency to mingle with the central portion of the current, while at the same time the steam-bubbles generated at the lower end of the tube continue to envelop the tube as they rise.

On account of the great difference in temperature of the gases as they enter and leave the tubes, the heating power of the tubes decreases rapidly toward the chimney-end. According to formula [III.] of this chapter the quantity of heat transmitted varies directly as the square of the difference of temperature at the two sides of a plate; in practice the efficiency of the tube-surface diminishes at a still greater rate, on account

of the greater accumulation of soot and scale at the chimney-end of the tubes. On the other hand, it must be observed that the same cause which produces the greater deposition of soot—viz., the diminished velocity of the gases (the volume of which decreases proportionally with the temperature, while the area of the tubes remains constant)—allows the gases also to remain a longer time in contact with the heating-surfaces.

Isherwood suspended various metals, the melting-points of which are well known, at different points in the chimney-ends of horizontal fire-tubes, and found that the temperature of the discharged gases is considerably higher at the upper than at the lower rows of tubes in the same boiler; he estimates that this difference of temperature is at times as high as 300°. This difference is probably due partly to the tendency of the hottest gases to rise to the highest point, partly to the fact that the mass of rising steam-bubbles envelops the upper tubes to a greater or less extent, while the lower tubes are surrounded by a more solid body of water.

When the gases enter the front smoke-connection, or uptake, in their passage to the chimney, their temperature must be reduced to a sufficiently low degree to cause no injury to the metal plates of the boiler, as these are no longer in contact with water, but with steam or air. Sometimes special provisions are made to utilize some of the heat of the escaping gases in superheating or drying the steam, by keeping them in contact with extensive surfaces surrounded by the steam.

6. Loss of Efficiency of Boilers by External Radiation and Conduction.—The heat radiated from the incandescent coal through the openings of the furnace-door and through the interstices of the grate is almost completely reabsorbed by the entering air. The temperature of the gases in the chimney is reduced to some extent by the radiation and conduction of heat from the smoke-pipe, and the draught of the boiler is correspondingly diminished; but the loss due to this cause is trifling in large boilers.

The loss of heat due to radiation and conduction from the shell of marine boilers may be reduced to a small amount by covering the shell with non-conductive materials, and by forming a dead-air space between the shell of the boiler and its covering.

The loss of heat by radiation and conduction from steam boilers, pipes, etc., has been determined by experiments made in the years 1863–65, under the direction of the Bureau of Steam Engineering of the United States Navy Department, which have been described and analyzed by Chief-Engineer Isherwood, U.S.N., in the *Journal of the Franklin Institute*, March, 1878.

The radiator used in these experiments was a flat box constructed of plate-iron $\frac{5}{16}$ inch thick. "The covering employed was the ordinary cow-hair felt, manufactured for clothing steam boilers, weighing one pound per square foot when $1\frac{1}{2}$ inches thick. It

was stitched tightly over the radiator so as to be in contact at all points, thereby preventing air-spaces, or air circulation, between the felt and the radiator." The thickness of the felt covering used in the experiments varied from ¼ inch to 7½ inches.

The experiments were made with steam-pressures varying between 10 and 60 pounds per square inch above the atmosphere, and the results showed that in still air, "*ceteris paribus, within the limits of the experimental temperatures, the quantity of heat radiated in equal times from the same surface with different temperatures on its opposite sides was in the direct ratio of their difference.*"

By plotting the mean final results for each set of experiments it was shown that the units of heat radiated per hour per square foot of surface per degree Fahrenheit difference of temperature on the opposite sides of the surface, varied almost exactly "in the inverse ratio of the square roots of the thicknesses of felt employed, from the thickness of 7½ inches up to the thickness of 1 inch, from which latter thickness up to naked metal the curve, though a fair one, followed no regular law."

Thickness in inches of the cow-hair felt on the air side of the boiler-plate iron.	Number of Fahrenheit units of heat lost per hour per square foot of boiler-plate iron, 5-16 inch thick, per degree Fahrenheit difference of temperature between that of the steam on one side of the metal and that of the still air upon the opposite side.
Naked	2.9330672000
0.25	1.0540710250
0.50	0.5728646875
0.75	0.4124625750
1.00	0.3070554725
1.25	0.2746387609
1.50	0.2507097171

Two experiments, each lasting 72 consecutive hours, were made to determine the *effect of covering the boiler with felt on the economic evaporation*, at the Navy-Yard, New York, in October, 1863, and are described by Isherwood in "Experimental Researches," Vol. II. The experimental boiler was of the locomotive type, and had 5.3066 square feet of grate-surface, 22.1 cubic feet of water-room, and 12.2 cubic feet of steam-room. The boiler stood in a shed of rough boards with one end open; the circulation of air around it was consequently considerably greater than would have been under the decks of a vessel. The experiments consisted in determining the economic evaporation of the boiler when covered with thick felt and when not covered, the conditions of the trials being otherwise as nearly as possible alike. The results of these experiments are summed up by Isherwood as follows:

"The number of pounds of water evaporated per hour during the experiment with the boiler not covered with felt was $\left(\frac{49504.640}{72}=\right)$ 687.565; and as we have seen that the addition of felt effected a saving of 22.05 per centum of this quantity, we have $(687.565 \times 0.2205 =)$ 151.608 pounds of steam condensed per hour by its omission. The external surface of the boiler from which heat was radiated was 94.09 square feet, consequently $\left(\frac{151.608}{94.09}=\right)$ 1.6113 pounds of steam were condensed per hour per square foot of unfelted surface. The temperature of the water and steam within was 267° Fahr., and of the external atmosphere 53.5°. The thickness of the boiler-plate was one-quarter inch."

The writer also calls attention to the fact that the per centum of condensation due to radiation from the external surface of the boiler will be greatly less for large boilers "and in proportion to size, because, while for similar boilers the external surface increases as the square of any dimension, the contents increase as the cube of the same dimension, and the steam-producing capability is as the contents."

7. Efficiency of Boilers.—The efficiency of a boiler is measured by the ratio borne by the quantity of heat expended in heating and vaporizing the water to the quantity of heat representing the calorific power of the fuel consumed.

The quantity of heat usefully expended in raising the temperature and vaporizing the water is the difference between the quantity of heat generated in the furnace and the quantity of heat present in the gases discharged from the chimney, less the quantity of heat lost by external radiation and conduction.

The efficiency of the furnace determines the total quantity of heat generated, and the weight and temperature of the products of combustion. (*See section* 13, *chapter* ii.)

The efficiency of the heating-surface determines the temperature of the gases discharged from the chimney. (*See section* 5 *of the present chapter.*)

The loss of efficiency due to external radiation and conduction has been discussed in *section* 6 of the present chapter.

Ordinarily from 20 to 33 per cent. of the total heat of combustion is expended in the production of chimney-draught in marine boilers. The additional losses of heat by radiation, by the incomplete combustion of the solid or gaseous parts of the fuel, and by the dilution of the gases of combustion with an excess of air reduce the amount of heat available for heating the water to about 60 per cent. of the total heat of combustion in average practice with marine boilers.

"When the draught is produced by means of a blast-pipe or of a blowing-machine no elevation of temperature above that of the external air is *necessary* in the chimney; therefore furnaces in which the draught is so produced are capable of greater economy than those in which the draught is produced by means of a chimney. It appears, further, that with a forced draught there is less air required for dilution, consequently a higher temperature of the fire, consequently a more rapid conduction of heat through the heating-surface, consequently a better economy of heat than there is with a chimney-draught." (*Rankine.*)

The following formula has been devised by Rankine to express "to an approximate degree of accuracy" the efficiency of a boiler:

$$\frac{E'}{E} = \frac{B\,S}{S + A\,F} \quad \text{[IV.]}$$

E denotes the theoretical evaporative power, and E' the actual evaporative power of one pound of a given sort of fuel consumed in a boiler; B and A are constants, which are found empirically; "the value of A is probably proportional approximately to the *square* of the quantity of air supplied per pound of fuel"; S denotes the number of square feet of heating-surface *per square foot of grate*, and F the number of pounds of fuel burned per hour *per square foot of grate.*

"The following are the values of the constants B and A which have been found to agree best with experiment, so far as the practical performance of boilers has hitherto been compared with the formula:

	B	A
Boiler Class I. The convection taking place in the best manner, either by introducing the water at the coolest part of the boiler and making it travel gradually to the hottest, or by heating the feed-water in a set of tubes in the uptake; the draught produced by a chimney, ...	1	0.5
Boiler Class II. Ordinary convection and chimney-draught, ...	$\frac{11}{12}$	0.5
Boiler Class III. Best convection and forced draught, ...	1	0.3
Boiler Class IV. Ordinary convection and forced draught, ...	$\frac{19}{20}$	0.3

"When there is a feed-water heater its surface should be *included* in computing S." . . . "The formula is framed on the supposition that the admission of air and the management of fire are such that no appreciable loss occurs, either from imperfect combustion or from excess of air, the construction and proportions of the furnace, and the mode of using it, being the best possible for each kind of coal." (*Rankine.*)

8. Influence of the Rate of Combustion on the Evaporative Efficiency of Boilers (*Isherwood*, '*Experimental Researches*,' vol. ii.)—"The economic and potential evaporations of boilers, other things equal, are greatly affected by the rate of combustion. With each increase in that rate above about 5 pounds of combustible per square foot of grate per hour, the economic evaporation decreases and the potential evaporation increases." . . . "In the following table will be found (for the horizontal fire-tube boiler, with the tubes above the furnace) the principal results due to different rates of combustion, varying from 6 to 24 pounds of anthracite per square foot of grate-surface per hour, supposing its refuse to be one-sixth." . . . "The calorimeter is taken at one-eighth of the grate-surface, and the heating-surface at 25 times the grate-surface. The economic evaporation is given in pounds of water evaporated under atmospheric pressure from 212° Fahr. per pound of anthracite. The economic evaporation is also

TABLE VII.

SHOWING THE ECONOMICAL AND POTENTIAL EVAPORATION OF THE HORIZONTAL FIRE-TUBE BOILER WITH ANTHRACITE CONSUMED WITH DIFFERENT RATES OF COMBUSTION.

Pounds of anthracite consumed per hour per square foot of grate-surface.	Pounds of water evaporated under atmospheric pressure from 212° Fahr. by one pound of anthracite.	Per centum of the total heat developed by the combustion, utilized evaporatively.	Temperature in degrees Fahr. of the products of combustion when leaving the boiler.	Weights of steam furnished by the boiler in equal time, expressed proportionally.	Weights of steam furnished by equal weights of anthracite, expressed proportionally.	Weights and bulks of anthracite required to furnish equal weights of steam, expressed proportionally.
6	10.49	84.42	444.7	1.0000	1.0000	1.0000
7	10.44	84.01	454.8	1.1611	0.9952	1.0048
8	10.35	83.59	472.6	1.3124	0.9867	1.0135
9	10.23	82.33	496.3	1.4628	0.9752	1.0254
10	10.05	80.88	532.0	1.5967	0.9580	1.0438
11	9.81	78.95	579.6	1.7145	0.9352	1.0693
12	9.53	76.69	635.5	1.8169	0.9085	1.1007
13	9.21	74.12	699.0	1.9023	0.8780	1.1389
14	8.87	71.38	766.6	1.9730	0.8456	1.1826
15	8.52	68.56	836.3	2.0305	0.8122	1.2312
16	8.21	66.07	897.7	2.0871	0.7826	1.2778
17	7.95	63.98	949.3	2.1473	0.7579	1.3194
18	7.70	61.97	999.0	2.2021	0.7340	1.3624
19	7.48	60.19	1042.9	2.2580	0.7131	1.4023
20	7.32	58.91	1074.5	2.3260	0.6978	1.4331
21	7.16	57.62	1106.4	2.3890	0.6825	1.4652
22	7.04	56.65	1130.3	2.4608	0.6711	1.4901
23	6.92	55.69	1154.0	2.5288	0.6597	1.5158
24	6.82	54.88	1174.0	2.6006	0.6501	1.5382

expressed in 'Per centum of the Total Heat developed by the Combustion, utilized evaporatively.' This is calculated on the supposition that the theoretical economic evaporation of the pound of anthracite with one-sixth of refuse is 12.4263 pounds of water under atmospheric pressure from 212° Fahr. . . . From these per centum—and assuming the temperature of the products of combustion in the furnace, at the moment of their formation, to be 2,469° Fahr. above that of the atmosphere (taken at 60° Fahr.), due to an air-supply of twice that which is chemically necessary for perfect combustion—the temperature of the products of combustion, when leaving the boiler, is easily calculated." . . . "The quantities in the second column of the table—namely, the pounds of water evaporated under atmospheric pressure from 212° Fahr. by one pound of combustible—are the means given by a careful collation of the results of all the experiments with the respective boilers."

9. Superheated Steam.—When the saturated steam generated in a boiler is brought into contact with heating-surfaces the absorbed heat will, in the first place, vaporize the particles of water held in suspension in the mass of steam, or, in other words, *dry* the steam; and any additional heat absorbed by the dry steam will raise its temperature above the boiling-point corresponding to its pressure, or, in other words, *superheat* the steam.

The experiments made by Tate and Fairbairn on the density of superheated steam showed "that, for temperatures within about 10° Fahr. of the saturation-point, the rate of expansion [of superheated steam] very greatly exceeds that of air; whereas at higher temperatures the rate of expansion very nearly approaches that of air. Hence it would appear that for some degrees above the saturation-point the steam is not decidedly in an aeriform state, or, in other words, that it is watery, containing floating vesicles of unvaporized water."

By drying and superheating steam its dynamic efficiency in the engine is increased, and fuel is economized in consequence. Comparing the efficiency of superheated steam with that of dry saturated steam, Rankine calculates that, in an engine using steam of an initial pressure of 34 pounds on the square inch and expanding it to five times its original volume, by superheating the steam so as to raise its temperature from 257°.5 to 428° a saving of about 15 per cent. would be effected; and, in case the *whole* of the superheating is effected by heat which would otherwise have been wasted, the saving would be about 23 per cent. In practice a still greater saving has frequently been effected by the introduction of superheaters, even when a more moderate degree of superheating was employed—probably in consequence of the additional increase in efficiency due to drying the steam.

The following are some of the results of Isherwood's experiments with superheated steam recorded in 'Experimental Researches,' vol. ii.:

In the U. S. S. *Mackinaw* the superheating was effected by carrying the water-level from 4 to 6 inches below the upper tube-plate in the "Martin" boiler. When the steam was cut off at 0.70 and 0.21 of the stroke of the piston from the commencement, the gain by superheating was 34.02 per centum and 38.85 per centum of the cost with saturated steam, respectively.

In the U. S. S. *Eutaw* the superheating apparatus described in section 3, chapter xii., was used. With an expansion due to cutting off the steam at 0.32 of the stroke of the piston from the commencement the cost of the indicated horse-power was 8.67 per centum less with steam superheated 79°.7 Fahr. than with saturated steam. With an expansion due to cutting off the steam at 0.58 of the stroke of the piston from the commencement the cost of the indicated horse-power was 14.76 per centum less with steam superheated 123°.2 Fahr. than with saturated steam.

In the steamer *Georgeanna* the superheating was effected partly in the steam-drum surrounding the uptake, and partly in a system of pipes within the uptake. The steam-superheating surface in the steam-drum alone, amounting to 299 square feet, was sufficient to impart enough additional heat to the steam not only to prevent all condensation of it in the cylinder due to any cause whatever, but to enable it to reach the end of the stroke of the piston in a superheated state; and this amount of superheating increased the economic efficiency of the steam two-eighths above that due to it as saturated steam.

The superheating-pipes and the steam-drum combined, containing an aggregate heating-surface of 900 square feet, raised the temperature of the steam as it entered the cylinder to 335° Fahr., while its pressure varied between 20 and 30 pounds per square inch above the atmosphere; and the economic efficiency of the steam was increased thereby three-eighths above that due to it as saturated steam.

"The greater the degree of superheating the greater will be the gain, but not *pro rata*. . . . The benefits derived from superheating, for a given number of degrees, are much greater at the commencement of the superheating than at the end, because the rate of expansion is higher near the saturation-point, because the prevention of condensation in the cylinder is completed with a very moderate amount of superheating, and because the loss from radiation is less. Practically, too, more steam is lost by leakage, with the same pressure, past the cylinder-piston and valves the more it is rarefied by the superheating; and after a certain temperature is reached the friction of the piston is materially increased by additional increments, and by tighter packing rendered

necessary to prevent excessive leakage." (*Isherwood*, '*Experimental Researches*,' vol. ii.)

On account of these practical difficulties it is not considered advisable to let the temperature of superheated steam exceed greatly 300° Fahr. When the temperature of saturated steam exceeds that point it is better to add only enough heat to the steam after it is generated to dry it, and to prevent condensation in the cylinders by steam-jackets.

10. Efficiency of Superheating-surfaces.—The term "*superheating-surface*" is applied to all heating-surfaces passing through the steam-room of a boiler.

According to section 5 of the present chapter a superheating apparatus would be most efficient—that is to say, transmit the greatest proportion of the total available heat per unit of surface—if placed at the hottest part of the furnace. The superheating apparatus is, however, usually placed in the uptake of the boiler, where it absorbs a portion of the heat of the escaping gases. In some cases special furnaces have been used for superheating the steam.

Two methods of superheating steam in boilers may be distinguished—viz., either all the steam which is generated passes through the superheating apparatus placed between the boilers and the engines, or only a portion of the steam which is generated enters the superheater, and is mixed in greater or less proportions with the saturated steam coming directly from the boilers before it passes to the engines. The latter method was introduced by Wethered, and the degree of superheating can be regulated by it to a great nicety.

In calculating the gain in the efficiency of a boiler by the addition of superheating-surface the heat absorbed in drying the steam has to be regarded as expended in evaporating an additional amount of water. The addition of superheating-surface in the uptake frequently increases the economic evaporative efficiency of the boiler at the expense of its potential evaporative efficiency (because the chimney-temperature is lowered, and the additional heating-surface offers an additional amount of resistance to the escaping gases), unless without the superheating-surface the temperature would exceed the limit given in section 11, chapter ii.

Isherwood found that by properly proportioned water-heating surfaces the evaporation in the boilers of the *Georgeanna* (see section 9 of the present chapter) could have been 16.5 per centum greater for the same amount of coal. "Now, we have seen the gain by superheating in the case of the *Georgeanna* to be three-eighths of the effect of saturated steam from her boiler; consequently we find that it is more economical to expend heat in superheating steam after it is generated than in generating its equivalent

of saturated steam, by (37.5 — 16.5) = 21 per centum. It is therefore advantageous, by this amount, to provide a separate superheating apparatus, and superheat the steam in it by the direct expenditure of fuel, in those cases in which it is not allowable to place the superheater in the uptake on account of the height required—very objectionable in war-steamers—taking care at the same time to employ a type and proportion of boiler that will give the maximum evaporation." (*Isherwood*, '*Experimental Researches*,' vol. ii.)

Practically considered, the value of superheaters depends, as far as the boilers are concerned, not only on the economic and potential evaporative efficiency of the latter, but on the additional bulk, weight, and cost of the superheating apparatus, on the labor and expense of keeping it in working order, and on its liability to derangement.

TABLE VIII.

SHOWING PROPERTIES OF WATER AND OF STEAM.

(*From Isherwood's 'Experimental Researches,' vol. ii.*)

Total pressure of steam in lbs. per sq. inch.	Temperature in degrees Fahrenheit. $T°$.	Total units of heat per pound of water from 32° to $T°$ Fahrenheit.	Total units of heat per pound of steam from 32° to $T°$ Fahrenheit.	Latent units of heat per pound of steam.	Weight of steam per cubic foot in fractions of a pound.	Cubic feet of steam per pound.	Volume of steam, water at 39°.1 being unity.
1	101.36	69.4305	1112.8548	1043.4243	.0034692	288.2475	17983.200
5	162.51	130.8914	1131.5055	1000.6141	.0136650	73.1806	4565.597
10	193.20	161.8704	1140.8660	978.9956	.0262900	38.0373	2373.075
14 69	212.00	180.9000	1146.6000	965.7000	.0380071	26.3109	1641.424
15	213.04	181.9540	1146.9172	964.9633	.0387839	25.7839	1608.607
20	227.95	197.0789	1151.4647	954.3858	.0511491	19.5507	1219.729
25	240.07	209.3952	1155.1613	945.7661	.0633879	15.7760	984.236
30	250.26	219.7656	1158.2693	938.5037	.0755004	13.2450	826.327
35	259.22	228.8964	1161.0021	932.1057	.0874913	11.4298	713.084
40	267.17	237.0076	1163.4268	926.4192	.0993593	10.0645	627.903
45	274.33	244.3208	1165.6106	921.2898	.1111084	9.0002	561.506
50	280.89	251.0279	1167.6114	916.5835	.1227283	8.1473	508.292
55	286.96	257.2400	1169.4628	912.2228	.1342847	7.4469	464.695
60	292.58	262.9967	1171.1769	908.1802	.1456581	6.8654	428.319
65	297.84	268.3892	1172.7812	904.3920	.1569473	6.3716	397.510
70	302.77	273.4473	1174.2848	900.8375	.1681290	5.9479	371.076
75	307.42	278.2219	1175.7946	897.5727	.1791958	5.5805	348.156
80	311.86	282.7841	1177.0573	894.2732	.1901576	5.2588	328.086
85	316.08	287.1234	1178.3444	891.2210	.2010112	4.9748	310.368
90	320.10	291.2597	1179.5705	888.3108	.2118493	4.7222	294.610
95	323.94	295.2134	1180.7417	885.5283	.2224107	4.4961	280.506
100	327.63	299.0150	1181.8671	882.8521	.2329599	4.2926	267.806
105	331.18	302.6750	1182.9499	880.2748	.2434062	4.1084	256.313
110	334.59	306.1920	1183.9899	877.7979	.2537549	3.9408	245.860
115	337.89	309.5979	1184.9964	875.3985	.2640060	3.7878	236.313
120	341.06	312.8713	1185.9633	873.0920	.2742161	3.6475	227.560
125	344.13	316.0433	1186.8996	870.8563	.2842203	3.5184	219.506
130	347.11	319.1238	1187.8085	868.6847	.2941889	3.3992	212.068
135	350.02	322.1355	1188.6961	866.5606	.3040635	3.2881	205.181

CHAPTER IV.

MATERIALS.

1. Relative Value of Materials for Boiler-construction.—In selecting materials for boiler-construction it is necessary to consider their strength under different conditions of stress, form, and temperature; their adaptability for being manufactured into the required forms; their behavior when exposed to heat, their cost, their durability, and their weight.

I. Regarding the strength of materials, it is not sufficient to consider the tensile or compressive strain which a small bar or block of regular section can bear in the testing-machine; in boilers the materials are chiefly employed in the form of thin plates, presenting either flat surfaces of great extent or curves and angles of every form, and from the manner of their connection and the conditions obtaining in the use of boilers they are exposed to a great variety of irregular strains. The vast amount of potential energy stored up in the steam and heated water of a boiler demands the employment of a material possessing a high degree of toughness, in order to mitigate the disastrous consequences of a rupture; for, while a tough material simply tears, brittleness would allow large pieces to be detached and hurled with great violence.

In this connection it must be observed that most metals, like copper, wrought-iron, and steel, possessing a high degree of toughness, may become brittle by drawing, rolling, and hammering, in consequence of a structural change undergone during such process; the original toughness can be restored, however, by annealing. The strains produced by unequal expansion, in consequence of the great difference of temperature existing at different parts of the boiler, require special attention.

II. The fitness of different materials for casting, rolling, and welding, as well as their behavior when subjected to reheating for bending, to punching, drilling, and riveting, require consideration. It is very important that the material should be of a reliable character, sound throughout, and of uniform strength.

III. The thermal conductivity of different materials, as well as their strength at the temperatures obtaining in steam boilers, varies greatly.

IV. The cost of materials is not measured merely by the market price of the raw pigs or ingots, sheets, and bars, but it is enhanced, for different materials in a widely different degree, by the difficulties encountered during the processes which convert them into constituent parts of a boiler. The final cost of a boiler is modified considerably by its durability as well as by the value of the old material.

V. Durability, the power of resisting the destructive effects of the various stresses and chemical agencies to which boilers are exposed, is of importance not only in so far as it affects their cost but also their efficiency; especially in the boilers of war-vessels that have to maintain their efficiency while engaged, for many months continuously, on distant stations without adequate facilities for repairs.

VI. The problem of producing the maximum effect with the minimum weight of material is of increasing importance in modern marine engineering, especially for war-vessels.

There is no substance that will pre-eminently satisfy all the foregoing requirements, and the selection of the proper material for different parts of a boiler has to be governed by experience as to their special fitness, and by the exercise of judgment as to the relative value of their properties in each case. Since wrought-iron has been for many years the principal material employed in boiler-construction, it is convenient to use it as a standard for measuring the relative fitness of other metals for this purpose.

2. Copper.—Copper was largely used for the shell of boilers when steam of comparatively low pressure was employed. Wilson says that the advantages possessed by copper for boiler-making consist "in the uniformity and homogeneity of its texture, in its freedom from lamination and blisters, and in its general trustworthy character when well selected; in the manner in which it resists the tenacious adhesion of most kinds of incrustation; in its great ductility and malleability, which render it capable of being worked with great ease and of bearing sudden as well as oft-repeated racking strains; in its being a better conductor of heat, which not only tends to give it a higher evaporative power under favorable conditions, but also enables it to last longer when exposed to a fierce wasting heat in a boiler-furnace." An explosion generally results in a simple tearing, and not in a violent projection of fragments; small leaks are easily calked; finally, as old material, copper is worth about two-thirds as much as when new.

On the other hand, copper deteriorates more rapidly than iron when coal containing sulphur or ammonia is burned in contact with it; its strength is inferior to that of iron nearly in the proportion of three to five at ordinary temperatures, but decreases rapidly with each increase of temperature. Experiments made by a committee of the Franklin Institute in 1837 developed the fact that at a temperature of 550° it loses one-fourth

of its tenacity at ordinary temperatures, at 817° precisely one-half, and at 1,000° two-thirds of its strength are destroyed. Its first cost is very high, being nearly five times that of iron. (See also chapter i.)

At present the use of copper in boilers is almost entirely limited to the crown-sheets of English locomotives, and, in marine boilers, to superheating-tubes, to feed, steam, blow, and escape pipes, and similar appendages.

3. Composition.—Composition is a general term for certain alloys of copper and tin or zinc, mixed in various proportions; they are harder and generally more tenacious than copper, and less subject to oxidation; they are more fusible than copper, make better castings, and are more easily worked with cutting tools, while at the same time their cost is less.

Brass is an alloy of copper and zinc. The quantity of copper varies from 60 to 92 per cent.; the best proportion for fine yellow brass appears to be, copper two parts and zinc one part. The addition of a little lead—from ½ to 3 per cent.—causes the brass to be more ductile and better adapted for turning in a lathe, but reduces the tenacity of the metal; a larger addition of lead renders the metal brittle. Instead of lead tin is sometimes added, which renders the metal more homogeneous and increases its fluidity without impairing its tenacity. Brass is more malleable than copper when cold, but cannot be forged at a red heat, on account of the low melting-point of zinc. It is very extensively used for castings and for brazed and drawn pipes and tubes.

Drawn seamless boiler-tubes have almost entirely superseded iron tubes in the vessels of the United States Navy. Their thermal conductivity is greater than that of iron in the proportion of 1.4 to 1, and their superior ductility makes it possible to render their joints tight without straining the metal to an undue degree; at the same time brass tubes can be made about 20 per cent. thinner than iron ones, while their freedom from corrosion gives them a reliability and durability which far outweigh their original increased cost over that of iron.

Bronze. Such parts of the machinery of United States naval vessels as require a high degree of tenacity combined with freedom from corrosion and lightness are made of a composition consisting of 88 parts of copper, 10 parts of tin, and 2 parts of zinc.

By adding a small portion of dry phosphorus to these alloys in the crucible, before running them into the mould, they are rendered so liquid that very thin and sound castings may be obtained, while at the same time the hardness and the tenacity of the metal are considerably increased.

Where expense is a secondary consideration, and where it is specially desirable to avoid corrosion and lessen weight, the use of composition is extended to valve-cham-

bers, pipes, screw-swivels for long braces intended to be removable, hinges of connection-doors, manhole-plates, etc. When exposed to a temperature approaching a red heat this metal loses all tenacity and crumbles to pieces.

4. Tenacity of Metals at various Temperatures (abridged from an article in the *Engineer*, Oct. 5, 1877).—The accompanying table gives the results of a series of experiments made in Portsmouth Dockyard to ascertain the loss of strength and ductility in gun-metal compositions when raised in temperature. The object was to see whether gun-metal would be more or less suitable than cast-iron for stop and safety valve boxes, steam-pipe connections, fastenings, etc., etc., which might be subjected to high temperatures, either from superheated steam or proximity to hot uptakes or funnels. The result shows that it is desirable to make further investigations. The specimens and dies for griping them were heated in an oil bath, and the temperatures recorded are those of the oil. In the case of gun-metal three or more tests were made at each temperature, the table giving the mean, except when there were defects in the metal. All the composition specimens were run in a horizontal position with a head of 2½ inches, excepting those in columns 1 and 2. Those in No. 2 were stronger at atmospheric temperature than No. 1, and they suffered sooner by increases of temperature. All the varieties of gun-metal suffer gradual but not serious loss of strength and ductility up to a certain temperature, at which, within a few degrees, a great change takes place; the strength falls to about one-half, and the ductility is wholly gone. Above this point, up to 500°, there is little if any further loss of strength. The precise temperature at which the change and loss of strength take place, although uniform in the specimens cast from the same pot, varies about 100° in the same composition at different temperatures or with some varying conditions in the foundry process. In No. 1 series this temperature was about 370°, and in No. 2 a little over 250°. The cause is not known, but the fact is certain and important. Phosphor-bronze, the only metal in the series which, from its strength and hardness, could be used as a substitute, was less affected by temperature, and at 500° retains more than two-thirds of its strength and one-third its ductility; but the difference arising from variations in the process of casting or quality of material used should be tested, also whether the other compositions may be hardened without loss of strength. Rolled Muntz metal and copper are satisfactory up to 500°, and may safely be used as securing-bolts. Wrought-irons increase in strength up to 500°, but lose slightly in ductility up to 300°, where an increase begins and continues up to 500°, where it is still less than at the ordinary temperature of the atmosphere. The strength of Landore steel is not affected by temperature up to 500°, but its ductility is reduced more than one-half.

TABLE IX.

Tenacity of various Metals at different Temperatures up to 500° Fahrenheit.

Constant of Machine, 50.25.

Temperature.	Gun-metal rods 1 in. diameter.												Phosphor-bronze rods 1 in. diameter.		Muntz-metal rods .74 in. diameter.		Copper rods .72 in. diameter.		Cast-iron rods 1 in. diam.		Wrought-iron.					
	1.		2. Second set.		3.		4.		5.		6.										Remanufactured rods .74 in. diam.		Yorkshire rods .70 in. diam.		Landore steel strips .74 in. by .49 in.	
	Copper 87.75, Tin 9.75, Zinc 2.50		Copper 87.75, Tin 9.75, Zinc 2.5		Copper 91, Tin 7, Zinc 2		Copper 85, Tin 5, Zinc 10		Copper 83, Tin 2, Zinc 15		Copper 92.5, Tin 5, Zinc 2.5		Copper 92.5, Tin 7, Phos. .5		Copper 62, Zinc 38				Welsh .25, Scotch .25, Scrap .50							
	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.	Tensile.	Ductility.
Fahr.	lbs.	* Per ct.	lbs.	* Per ct.	lbs.	* Per ct.	lbs.	* Per ct.	lbs.	* Per ct.	lbs.	* Per ct.	lbs.	* Per c.	lbs.	* Per c.	lbs.	* Per c.	lbs.	* Per c.	lbs.	* Per c.	lbs.	* Per c.	lbs.	Per c.
atmospheric.	535	12.5	575	8.75	525	16	525	21	485	26	560	20	609	17.5	700	2.5	460	2.5	480	nil.	500	22	460	25	555	26
100°	505	10	....	....	525	15.5	550	18	480	26	...	....	614	17	680	2.5	465	2.5	423	"	530	18.75	460	24.25	....	....
150°	525	11	....	....	525	14	530	19.5	450	25.5	....	....	610	18	720	3.9	445	4	441	"	530	15	....	....	....	....
200°	485	10	535	8.75	460	9	523	19	460	26.25	440	11	605	18	685	3.9	440	5	440	"	530	15	465	17.25	535	22.5
250°	505	10	385	5	255	3	515	16	440	26	360	6	580	15	670	5	430	7	470	"	540	15	....	....	....	....
300°	500	10	295	.66	265	nil.	531	18.25	435	23	255	.66	575	12	650	2.5	430	6	490	"	650	15.5	480	7.5	555	11.25
350°	450	8.25	295	nil.	....	....	495	17	435	25	....	...	470	7	650	2.25	430	6	470	"	660	12.5	....	....	...	....
400°	245	.75	....	....	260	nil.	260	2	435	25	....	....	424	5	600	2.25	420	6	401	"	640	12	465	15	590	10.25
450°	265	nil.	....	....	....	....	250	2	152	1.2	....	....	380	4	615	3.75	415	6	400	"	680	15	....	....	....	....
500°	250	nil.	....	....	275	nil.	230	2	152	nil.	....	....	420	5	620	5	390	6	400	"	680	20	550	13.75	600	10

* In a length of 10 inches.

Note: To find the tenacity of a bar in pounds per square inch, multiply the number in the column marked "*tensile*" by the constant of the machine, and divide the product by the cross-area of the bar in square inches.

5. Cast-iron.—Cast-iron is used for grate-bars, ashpans, furnace and uptake doors, manhole and handhole plates, valve-chambers, steam, feed, blow, and dry pipes, and other boiler appendages. Its low first cost and the ease with which it can be worked give it great advantages for such purposes; but the uncertainty of strength caused by defective moulding, its brittleness and low tensile strength, render it unfit for extensive use for parts of the boiler proper. Its unyielding nature unfits it specially for parts subjected to unequal expansion from differences of temperature. Several kinds of modern sectional boilers consist, however, almost entirely of small cast-iron spheres or tubes.

6. Wrought-iron.—Wrought-iron has been for many years the material most extensively used in boiler-making. Wilson sums up the advantages possessed by it for this purpose in the following words: "The great tensile strength of good wrought-iron, together with its ductility, power of bearing sudden and trying strains, and general trustworthy nature, its moderate facilities for working, the ease with which it can be welded, riveted, patched, or mended, its moderate first cost compared with copper, are all important advantages which contribute to its value."

It enters into the construction of boilers as plates, varying from $\frac{1}{4}''$ to $1\frac{1}{4}''$ in thickness, as rivets, round bar-iron and flat iron, T and angle iron, and drawn seamless and lap-welded tubes. In order to reduce the weight of boilers as much as possible wrought-iron is frequently used instead of cast-iron for furnace, ashpit, and uptake doors, for ashpans, manhole-covers, and sometimes for grate-bars.

The wrought-iron used in the construction of the boiler proper should be of the best quality; it must possess not only great tensile strength but a high degree of ductility, and it must bear, without receiving serious injury, the severe treatment to which it is subjected by repeated heating, welding, hammering, punching, and drilling. The quality of wrought-iron depends upon the chemical composition of the cast-iron or the ore from which it has been made, and of the fuel used during the process of conversion; on the thoroughness with which the slag, cinders, and other deleterious substances have been removed; and on the general care and labor expended on it during the processes of refining, squeezing, hammering, and rolling. The most common defect of boiler-plates arises from the imperfect welding of the several layers of metal forming the plate, owing to the interposition of sand or cinders; the laminations and blisters produced in this manner are sometimes difficult to detect, but will appear sooner or later when the plate is exposed to the intense heat of the furnace. The presence of a small trace of sulphur produces hot-shortness in iron, which means that it will not work advantageously and becomes brittle when red-hot, but is strong and pliable when

cold. On the other hand, the presence of phosphor and silicon produces cold-shortness, which means that the iron will not stand bending, twisting, or punching near the edges when cold. An increase in the percentage of carbon renders the iron harder, less ductile, and more difficult to weld.

During the process of rolling into bars or plates iron assumes a fibrous texture, and boiler-plates, as a rule, are stronger when the tension takes place in the direction of the fibre than when it is applied at right angles to the fibre. Increase of temperature does not diminish the strength of iron till it reaches about 400°.

7. Brands of Plate-iron used in Boiler-making.—The use of mineral fuel is generally dispensed with in the manufacture of boiler-iron, and wood charcoal is employed instead, in order to avoid the admixture of deleterious foreign substances. Such iron is designated by the name of "*charcoal-iron.*"

The following are the various brands of American plate-iron commonly used for marine boilers, arranged in the order of their excellence and cost: *Charcoal No.* 1 *Iron* (*C. No.* 1) will bear 40,000 lbs. tensile strain in the direction of the fibre; it is pretty hard and is never flanged; it is often used for the interior parts of a boiler, but breaks or furrows easily when exposed to bending strains. Another brand (*C. No.* 1 *R. H.*), *Charcoal No.* 1 *Reheated Iron*, is a very durable iron for fire-boxes, since, on account of its hardness, it resists the oxidizing influence of the flame; but it breaks easily under alternating bending strains.

Charcoal Hammered No. 1 *Shell-iron* (*C. H. No.* 1 *S.*), though not necessarily hammered, has been worked more thoroughly than the previous brands before it is rolled into plates. It will bear in the testing-machine from 50,000 lbs. to 54,000 lbs. of tensile strain per square inch in the direction of the fibre, and from 34,000 to 44,000 lbs. across the fibre. It is a rather hard iron and cannot be flanged; at least it should not be bent along the fibre, but always across the fibre and with a pretty large radius. It is used especially for the outside shell of boilers.

C. H. No. 1 *F.* (*Flange*) *Iron* is a soft material, which can be flanged in every direction. It will bear from 50,000 to 54,000 lbs. of tensile strain per square inch along the fibre, and the best qualities do not show a much smaller strength when the strain is applied across the fibre.

C. H. No. 1 *F. B.* (*Fire-box*) *Iron* is a harder quality, designed to withstand the destructive effect of the impinging flame; it will generally bear flanging. There is, however, another quality, marked *C. H. No.* 1 *F. F. B.* (*Flange Fire-box*) *Iron*, or *Extra Fire-box* or *Excelsior Fire-box Iron*, which is generally used for flanged fire-box plates.

There are special brands, as *Sligo*, *N. P. U. Iron* (made at the Lukens Rolling-mills, Coatesville, Chester Co., Pa.), *Eureka* (manufactured by C. E. Pennock & Co., Valley Iron-works, Coatesville, Pa.), and *Pine Iron*, which command high prices, and are specially fitted to withstand the destructive effect of heat or to be worked into the most difficult forms.

These "*charcoal-irons*" are manufactured principally in Pennsylvania.

The greatest width of boiler-plates made at different establishments varies between 48 inches and 96 inches, and the extreme weight of the trimmed plate between 1,000 and 1,800 lbs. The length of the plate varies frequently with the width; with some manufacturers it is the rule to deduct one inch in width for each additional foot in length: for instance, if the dimensions of the widest plates are 76″ × 76″, narrower plates would have the following dimensions: 75″ × 88″, 74″ × 100″, 73″ × 112″, etc.

The best English boiler-iron is the Yorkshire iron, which seems to owe its superiority partly to the fact that the coal used in the reduction of the ore and the manufacture of the plates is remarkably free from sulphur and phosphorus. Wilson says: "The most prominent makers of boiler-plates are the so-called 'Best Yorkshire' houses (viz., The Low Moor Iron-works, near Bradford; Taylor Brothers & Co., Leeds; Bowling Iron Co., near Bradford; Farnley Iron Co., near Leeds; S. T. Cooper & Co., Leeds; and The Monk Bridge Iron Co., Leeds; the other firms who make only 'Best Yorkshire' iron do not roll plates), who only turn out one class of iron, and that the very best, if we except some of the Swedish and Russian brands."

8. Steel.—The use of steel in boiler-construction has attracted much attention of late, especially since the introduction of improved processes of manufacture, which have resulted in the production of much more uniform qualities of steel than were formerly obtainable, and in a reduction of its cost which allows it to compete in many cases with wrought-iron in economical respects.

The steel used for boiler-plates is sometimes crucible steel, but is generally manufactured by the Bessemer or the Siemens-Martin process. It must be of a very mild quality, containing about one-quarter or one-third per cent. of carbon. Steels containing a larger amount of carbon possess greater tensile strength, but are brittle, hard to work, and untrustworthy for use in boiler-making. It is very important that steel boiler-plates do not temper when suddenly cooled down from a red heat. Steel loses this characteristic of taking a temper when the percentage of carbon is reduced below a certain amount, while at the same time its welding qualities are improved. In fact, the milder kinds of steel possess all the good qualities of wrought-iron, only in a higher degree, and differ from it principally by their greater purity and their perfectly

homogeneous structure. While iron boiler-plate is produced by the piling of a number of slabs, separately manufactured and undergoing repeated reheatings, steel plates are rolled from single ingots, often at one heat. Each charge of the hearth or converter produces from five to eight tons of metal, which can be carefully examined and tested, and carburized or decarburized and refined to any desired degree, before it is finally drawn off. In this manner a uniformity in the character of the metal is produced which is unattainable in the manufacture of iron. Wilson says that, "in order to ensure freedom from brittleness, from 33 to 36 tons per square inch appears to be the maximum tensile strength that can be allowed. Steel plates of this strength can be made sufficiently tough and ductile to render them safe and also tolerably easily worked." But the surveyors to Lloyd's Registry recommend that steel used in boiler-making should have an ultimate tensile strength of not less than 26 tons and not more than 30 tons per square inch of section, and the same limits have been adopted by the English Admiralty.

Even the mildest steels seem to be affected differently from iron by the severe strains of hammering, punching, and shearing; to restore to the plate its original character it is considered necessary to anneal it.

With regard to the effect of corrosion on steel the opinions are much divided; while the greater density and homogeneity of steel would lead one to suppose that it would suffer less than iron in that respect, it is asserted that steel boilers have shown an unusual amount of corrosion after short use. This question can only be settled after further experience with the qualities of steel now in use. In this connection it must be remembered that, since thin plates deteriorate more rapidly relatively than thicker plates under the influence of corrosion, the reduction in the thickness of steel boiler-plates cannot be made in the ratio of the increased strength of steel over iron.

The following extracts are taken from a report of the surveyors to Lloyd's Registry, made in the early part of 1878, which discusses the advantages and difficulties incident to the use of steel for boilers in a very thorough manner:

"The methods adopted in the manufacture of mild steel by the Bessemer and Siemens-Martin processes are such as practically to ensure the production of a material perfectly reliable so far as regards its uniformity in tensile strength and its power to withstand certain bending tests. The limit of elasticity of this material bears about the same relation to its ultimate strength as in ordinary wrought-iron; but the elongation or stretch under stresses proportional to the ultimate strengths is greater with steel than with iron—a fact which should not be lost sight of in forming an estimation of the strength of boilers. At first sight it recommends itself by its tensile strength, mallea-

bility, and ductility, and also by its freedom from laminations and blisters, as eminently suited for the construction not only of the shells and stays but also of the furnaces and combustion-chambers of marine boilers. But while as a material it possesses in a special degree these high qualities, it is found that they become seriously impaired by its being subjected to the processes usually occurring in boiler-making, and it is necessary to exercise the greatest care in the working of it to ensure these qualities being retained in the structure, while in some instances it is even requisite to subsequently employ special means in order to restore them. The simple process of shearing affects to some extent the tensile strength of the plate operated upon, and a considerable portion of its strength is lost by punching. It is contended, however, and indeed it may be said to be placed beyond doubt, that the loss thus occasioned is fully recovered by the plates being annealed after they have been sheared or punched, and it is the practice at almost all the steel manufactories we have visited to anneal every plate after it is sheared and before being sent out of the works. It may be well here to remark that this annealing is not, as is frequently supposed, a process of some difficulty, requiring great care and considerable time in the operation. It consists simply of heating the plates to a low red heat—which allows the particles that have been strained or disturbed by the working of the material to resume their normal condition—and then cooling them uniformly.

"At some works the holes are drilled, and at others punched; but in all cases in which they are punched the plates are afterwards annealed. It is the practice at all the works, and it is considered by these firms to be of the utmost importance to perform the operation of flanging in only one heat, if possible, and to have the plates uniformly heated throughout; but when this is not practicable, and the operation is extended over several heats—the plates being heated locally piece by piece, as is usually done in flanging iron plates—care is taken that the plates so flanged are afterwards annealed.

"The opinions of those who may be regarded as authorities on the matter differ greatly with regard to the limits of tensile strength which should be adopted for this material when intended for boiler-making purposes. . . . Taking into consideration the fact that the milder material is more easily worked and less likely to be injured by careless manipulation than that of higher strength and more brittle nature, . . . we are of the opinion that it would not be prudent, at least until further experience is gained, to raise the limits; while at the same time it might be advisable to recommend that plates used in the construction of the furnaces and combustion-chambers be specified to withstand not more than from 26 to 28 tons per square inch.

"With regard to the question of steel rivets, it has been conclusively shown, by the results of some of the experiments made on the Tyne, that they may be used with as

much reliability as steel plates, but that, like the latter, they require greater care and discrimination to be exercised in the working of them than those made of iron. In the opinion of Dr. Siemens and other authorities the material of which the rivets are made should be very mild steel, the tensile strength not exceeding 26 tons per square inch. It is also needful to heat them uniformly throughout their entire length, and not to raise the points to a higher temperature than the heads, as is the usual practice with iron rivets, and they should not be heated beyond a bright-red heat. When these precautions are taken steel rivets will be found to resist steady strains and also jars and concussions much better than iron rivets.

"In conclusion, we would remark that in the construction of steel boilers greater care and attention must be exercised with the workmanship than is required in the case of iron boilers ; and the difference between the two materials, and the consequent different manipulation required in each case, must be realized not only by the manager, but by the workman who will have to use the material; for if steel plates are drifted heavily and knocked about as iron plates usually are in boiler-making, the material will be injured. We may expect to see steel boilers extensively used in preference to those made of iron, where lightness or increased pressure is an object, while if they are made with the care which this material requires, and eventually prove to be as durable as iron boilers, it will be a question whether a considerable reduction in the factor of safety may not be found quite compatible with perfect safety and efficiency.

"After having given all the circumstances in connection with the whole matter our most careful consideration, we would respectfully submit that, where it is proposed to use steel boilers in vessels intended for classification in this society's Register Book, the requirements of the case would be met by sanctioning a reduction from the scantlings prescribed by the rules for iron boilers, in the shell-plates and stays to the extent of 25 per cent., and in the flat plates not subject to the action of heat to the extent of 12 per cent., under the following conditions:

"I. The material to have an ultimate tensile strength of not less than 26 tons nor more than 30 tons per square inch of section.

"II. A strip cut from every plate used in the construction of the furnaces and combustion-chambers, and strips cut from other plates taken indiscriminately, heated uniformly to a low cherry-red heat, and quenched in water of 82° Fahr., must stand bending to a curve of which the inner radius is not greater than one and one-half times the thickness of the plate tested.

"III. All holes to be drilled, or, if they are punched, the plates to be afterwards annealed.

"IV. All plates, except those that are in compression, that are dished or flanged, or in any way worked in the fire, to be annealed after the operations are completed.

"V. The boilers upon completion to be tested in the presence of one of the society's engineer-surveyors to not less than twice the working pressure."

TABLE X.

EXHIBITING CERTAIN PHYSICAL AND MECHANICAL PROPERTIES OF VARIOUS METALS.

Material.	Weight in pounds per cubic foot.	Expansion of unity of length from 32° to 212° Fahr.	Ultimate tensile strength.	Elongation in per cent. of length.	Shearing strength.	Crushing strength.
Cast-iron	444 R.	.0011 R.	....	....	....	....
American, average	....	....	20,000 W.	....	....	....
English, average	....	....	16,500 H.	....	27,700 R.	112,000 R.
Wrought-iron	480 R.	.0012 R.	....	....	....	....
Bar-iron, average	483 K.	....	56,500	....	50,000 R.	38,000 R.
Boiler-plate, average	....	....	51,000	....	....	....
Yorkshire boiler-plate	481 K.	....	....	....	....	....
" " in direction of fibre	....	....	55,433 K.	13.4	....	....
" " across the fibre	....	....	50,462 K.	6.0	....	....
Yorkshire bar-iron	484 K.	....	61,955 K.	24.46	....	....
English rivet-iron, average	....	....	61,469 K.	20.46	*46,144 B.	....
Swedish bar-iron	486 K.	....	46,747 K.	22.3	....	....
Steel	490 R.	.0012 R.	....	....	....	....
Landore steel boiler-plate	....	....	63,000	24.25	....	....
Fagersta steel boiler-pl., unannealed	....	....	51,528 K.	14.05 K.	....	....
" " annealed	....	....	47,750 K.	16.53 K.	....	....
" hammered bars, soft	....	....	61,312 K.	16.5 K.	....	121,333 K.
Cast-steel rivets, English (Moss & Gamble)	....	....	107,286 K.	12.4 K.	....	....
Krupp's bolt-steel	....	....	92,015 K.	15.3 K.	....	....
Copper	....	.00184 R.	....	....	....	....
Sheets	549 R.	....	30,000	....	....	....
Rolled bars	....	....	33,000 A.	....	....	....
Cast bars	548.6 T.B.	....	27,800 T.B.	6.47 T.B.	....	42,000 T.B.
Bronze	....	.00181 R.	....	....	....	....
96.06 C, 3.76 T	539.7 T.B.	....	32,000 T.B.	14.29 T.B.	....	42,000 T.B.
92.11 C, 7.80 T	542.5 T.B.	....	28,540 T.B.	5.53 T.B.	....	42,000 T.B.
90.27 C, 9.58 T	540.9 T.B.	....	26,860 T.B.	3.66 T.B.	....	38,000 T.B.
87.15 C, 12.73 T	541.7 T.B.	....	29,430 T.B.	3.33 T.B.	....	53,000 T.B.
80.95 C, 18.84 T	545.6 T.B.	....	32,980 T.B.	0.40 T.B.	....	78,000 T.B.
8 parts copper, 1 part tin	524 R.	....	36,000 A.	....	....	....
Brass (rolled): 3 copper, 2 zinc	525.4	....	49,280 A.	....	....	....
" (cast): 2 copper, 1 zinc	486.5	.00216 R.	28,900 A.	....	....	....

A = Anderson; H = Hodgkinson; K = Kirkaldy; R = Rankine; W = Wade; B = Brunel; T.B = U. S. Test Board; * = one experiment.

TABLE XI.

WEIGHT OF WROUGHT-IRON PLATES AND BARS. (*Square and Round.*)

TRAUTWINE.

Thickness or Diameter. Inches.	Weight of plates per square foot, in pounds.	Weight per foot of square bars, in pounds.	Weight per foot of round bars, in pounds.
1/4	10.10	.2105	.1653
9/32	11.37	.2665	.2093
5/16	12.63	.3290	.2583
11/32	13.89	.3980	.3126
3/8	15.16	.4736	.3720
13/32	16.42	.5558	.4365
7/16	17.68	.6446	.5063
15/32	18.95	.7400	.5813
1/2	20.21	.8420	.6613
9/16	22.73	1.066	.8370
5/8	25.26	1.316	1.033
11/16	27.79	1.592	1.250
3/4	30.31	1.895	1.488
13/16	32.84	2.223	1.746
7/8	35.37	2.579	2.025
15/16	37.89	2.960	2.325
1	40.42	3.368	2.645
1/16	42.94	3.803	2.986
1/8	45.47	4.263	3.348
3/16	48.00	4.750	3.730
1/4	50.52	5.263	4.133
5/16	53.05	5.802	4.557
3/8	55.57	6.368	5.001
7/16	58 10	6.960	5.466
1/2	60.63	7.578	5.952
5/8	65.68	8.893	6.985
3/4	70.73	10.31	8.101
7/8	75.78	11.84	9.300
2	80.83	13.47	10.58
1/8	85.89	15.21	11.95
1/4	90.94	17.05	13.39
3/8	95.99	19.00	14.92
1/2	101.00	21.05	16.53
5/8	106.10	23.21	18.23
3/4	111.20	25.47	20.01
7/8	116.20	27.84	21.87
3	121.30	30.31	23.81

TABLE XII.

Weight of Flat Bar-iron per Foot.

Width in inches.	Thickness in inches.											
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	.21	.42	.63	.84	1.05	1.26	1.47	1.68	2.11	2.53	2.95	3.37
$1\frac{1}{8}$	.24	.47	.71	.95	1.18	1.42	1.66	1.90	2.37	2.84	3.32	3.79
$1\frac{1}{4}$	.26	.53	.79	1.05	1.32	1.58	1.84	2.11	2.63	3.16	3.68	4.21
$1\frac{3}{8}$	.29	.58	.87	1.16	1.45	1.74	2.03	2.32	2.89	3.47	4.05	4.63
$1\frac{1}{2}$	.32	.63	.95	1.26	1.58	1.90	2.21	2.53	3.16	3.79	4.42	5.05
$1\frac{5}{8}$	.34	.68	1.03	1.37	1.71	2.05	2.39	2.74	3.42	4.11	4.79	5.47
$1\frac{3}{4}$	.37	.74	1.11	1.47	1.84	2.21	2.58	2.95	3.68	4.42	5.16	5.89
$1\frac{7}{8}$	.40	.79	1.18	1.58	1.97	2.37	2.76	3.16	3.95	4.74	5.53	6.32
2	.42	.84	1.26	1.68	2.11	2.53	2.95	3.37	4.21	5.05	5.89	6.74
$2\frac{1}{8}$	.45	.90	1.34	1.79	2.24	2.68	3.13	3.58	4.47	5.37	6.26	7.16
$2\frac{1}{4}$	.47	.95	1.42	1.90	2.37	2.84	3.32	3.79	4.74	5.68	6.83	7 58
$2\frac{3}{8}$	.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	5.00	6.00	7.00	8.00
$2\frac{1}{2}$	.53	1.05	1.58	2.11	2.63	3.16	3.68	4.21	5.26	6.32	7.37	8.42
$2\frac{5}{8}$	.55	1.11	1.66	2.21	2.76	3.32	3.87	4.42	5.53	6.63	7.74	8.84
$2\frac{3}{4}$	.58	1.16	1.74	2.32	2.89	3.47	4.05	4.63	5.79	6.95	8.10	9.26
$2\frac{7}{8}$	.61	1.21	1.82	2.42	3.03	3.63	4.24	4.84	6.05	7.26	8.47	9.68
3	.63	1.26	1.90	2.53	3.16	3.79	4.42	5.05	6.32	7.58	8.84	10.10
$3\frac{1}{4}$	.68	1.37	2.05	2.74	3.42	4.11	4.79	5.47	6.84	8.21	9.58	10.95
$3\frac{1}{2}$	.74	1.47	2.21	2.95	3.68	4.42	5.16	5.89	7.37	8.84	10.32	11.79
$3\frac{3}{4}$	.79	1.58	2.37	3.16	3.95	4.74	5.53	6.32	7.89	9.47	11.05	12.63
4	.84	1.68	2.53	3.37	4.21	5.05	5.89	6.74	8.42	10.10	11.79	13.47
$4\frac{1}{4}$	.90	1.79	2.68	3.58	4.47	5.37	6.26	7.16	8.95	10.74	12.53	14.31
$4\frac{1}{2}$	.95	1.90	2.84	3.79	4.74	5.68	6.63	7.58	9.47	11.38	13.26	15.16
$4\frac{3}{4}$	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	10.00	12.00	14.00	16.00
5	1.05	2.11	3.16	4.21	5.26	6.32	7.37	8.42	10.53	12.63	14.74	16.84
$5\frac{1}{4}$	1.11	2.21	3.32	4.42	5.53	6.63	7.74	8.84	11.05	13.26	15.47	17.68
$5\frac{1}{2}$	1.16	2.32	3.47	4.63	5.79	6.95	8.10	9.26	11.58	13 89	16.21	18.52
$5\frac{3}{4}$	1.21	2.42	3.63	4.84	6.05	7.26	8.47	9.68	12.10	14.53	16.95	19.37
6	1.26	2.53	3.79	5.05	6.32	7.58	8.84	10.10	12.63	15.16	17.68	20.21

TABLE XIII.

WEIGHT OF SHEET AND PLATE IRON.

Thickness.		Weight.	Thickness.		Weight.
B. W. gauge.	Fractions of an inch.	Pounds per square foot.	B. W. gauge.	Fractions of an inch.	Pounds per square foot.
36	.004	.126	11	.120	4.48
35	.005	.202		$\frac{1}{8}$ or .125	5.054
34	.007	.283	10	.134	5.426
33	.008	.322	9	.148	5.98
32	.009	.364		$\frac{5}{32}$ or .1562	6.305
31	.010	.405	8	.165	6.605
30	.012	.485	7	.180	7.27
29	.013	.526		$\frac{3}{16}$ or .1875	7.578
28	.014	.595	6	.203	8.005
27	.016	.677		$\frac{7}{32}$ or .2187	8.79
26	.018	.755	5	.22	8.912
25	.020	.811	4	.238	9.62
24	.022	.912		$\frac{1}{4}$ or .25	10.09
23	.025	1.018	3	.259	10.37
22	.028	1.137		$\frac{9}{32}$ or .2812	11.38
	$\frac{1}{32}$ or .03125	1.259	2	.284	11.525
21	.032	1.31	1	.3	12.15
20	.035	1.416		$\frac{5}{16}$ or .3125	12.58
19	.042	1.695	0	.340	13.750
18	.049	1.075		$\frac{11}{32}$ or .3437	13.875
17	.058	2.35		$\frac{3}{8}$ or .375	15.10
	$\frac{1}{16}$ or .0625	2.518	00	.380	15.26
16	.065	2.637		$\frac{13}{32}$ or .4062	16.34
15	.072	2.92	000	.425	17.125
14	.083	3.35		$\frac{7}{16}$ or .4375	17.65
	$\frac{3}{32}$ or .0937	3.78	0000	.454	18.30
13	.095	3.85		$\frac{15}{32}$ or .4687	18.90
12	.109	4.4	00000	$\frac{1}{2}$ or .50	20.00

For *steel plates* multiply the tabular number of any size by 1.01.

TABLE XIV.

WEIGHT OF WROUGHT ANGLE-IRON. (*C. W. & H. W. Middleton, Philadelphia.*)

Dimensions in inches.		Weight per foot in pounds.
Width.	Thickness.	
$\frac{3}{4} \times \frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{4}$
1×1	$\frac{3}{16}$	1 to $1\frac{1}{4}$
$1\frac{1}{8} \times 1\frac{1}{8}$	$\frac{1}{8}$ to $\frac{3}{16}$	$1\frac{1}{2}$ to $1\frac{3}{4}$
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{1}{2}$ to 2
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{3}{16}$ to $\frac{1}{4}$	$1\frac{3}{4}$ to $2\frac{1}{4}$
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{1}{4}$ to $\frac{5}{16}$	$2\frac{1}{4}$ to $4\frac{1}{2}$
2×2	$\frac{1}{4}$ to $\frac{3}{8}$	3 to 5
$2\frac{1}{4} \times 1\frac{1}{2}$	$\frac{3}{16}$ to $\frac{1}{4}$	$2\frac{1}{2}$ to 3
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{5}{16}$ to $\frac{3}{8}$	4 to 6
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{5}{16}$ to $\frac{3}{8}$	5 to 10
$2\frac{3}{4} \times 2\frac{3}{4}$	$\frac{5}{16}$ to $\frac{3}{8}$	6 to 8
3×2	$\frac{1}{4}$ to $\frac{5}{16}$	4 to 5
$3 \times 2\frac{1}{2}$	$\frac{5}{16}$ to $\frac{1}{2}$	$5\frac{1}{3}$ to $8\frac{1}{3}$
3×3	$\frac{3}{8}$ to $\frac{1}{2}$	$7\frac{1}{4}$ to 10
$3\frac{1}{4} \times 2$	$\frac{1}{2}$	$6\frac{1}{2}$ to 8
$3\frac{1}{2} \times 3$	$\frac{3}{8}$ to $\frac{9}{16}$	$7\frac{2}{3}$ to 11
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{1}{2}$ to $\frac{5}{8}$	9 to 12
4×3	$\frac{1}{2}$	$8\frac{1}{4}$ to 12
$4 \times 3\frac{1}{2}$	$\frac{3}{8}$ to $\frac{9}{16}$	9 to 13
4×4	$\frac{1}{2}$ to $\frac{5}{8}$	11 to 15
$4\frac{1}{2} \times 3$	$\frac{3}{8}$ to $\frac{9}{16}$	9 to 13
5×3	......	13
$5 \times 3\frac{1}{2}$	......	$13\frac{1}{2}$
5×4	......	$14\frac{1}{2}$ to 20
$6 \times 3\frac{1}{2}$	$\frac{3}{4}$	22
6×4	$\frac{1}{2}$ to $\frac{7}{8}$	14 to 27
$6\frac{1}{2} \times 4$	$\frac{7}{16}$ to $\frac{5}{8}$	$14\frac{2}{3}$ to $20\frac{2}{3}$

TABLE XV.

WEIGHT OF WROUGHT T-IRON. (*C. W. & H. W. Middleton, Philadelphia.*)

Dimensions in inches.	Weight per foot in pounds.
1 × 1	¾ to 1
1¼ × 1¼	1½ to 2
1½ × 1¼	3
1½ × 1½	2 to 2½
1¾ × 1¼	3
1¾ × 1¾	2¾
2 × 2	3¼
2¼ × 2¼	3¾
2½ × 1¼	2½
2½ × 2½	5¼
2½ × 2¾	6¼
2¾ × 1¾	6¼
3 × 3	6½ to 9
3 × 3½	10¾ to 11
3 × 4	11 to 12
3½ × 3	10 to 11
3½ × 3½	10 to 12
3½ × 4	13½
4 × 2	6½ to 8
4 × 4	12
4 × 4½	13
4 × 5	14
5 × 2½	10 to 12
5 × 3	11 to 14

TABLE XVI.

Wrought-iron Bolts with Square Heads and Nuts.

(*C. W. & H. W. Middleton, Philadelphia.*)

Weight in pounds of 100 of the enumerated sizes.

Lengths.	$\frac{1}{4}$ in.	$\frac{3}{8}$ in.	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	$\frac{7}{8}$ in.	1 in.	$1\frac{1}{8}$ in.
Inches.								
$1\frac{1}{2}$	4.16	10.62	23.87	39.31	.....	.....	...	...
$1\frac{3}{4}$	4.22	11.72	25.06	41.38	.....	.....	...	...
2	4.75	12.38	26.44	45.69	73.62	.....	...	...
$2\frac{1}{4}$	5.34	12.90	28.62	49.50	76.	.....	...	...
$2\frac{1}{2}$	5.97	14.69	29.50	51.25	79.75	.....	...	...
$2\frac{3}{4}$	6.50	16.47	31.16	53.	83.	.....	...	...
3	....	17.87	32.44	56.	85.38	127.25	...	...
$3\frac{1}{2}$	....	18.94	39.75	63.12	93.44	140.56	...	...
4	....	20.59	42.50	74.87	108.12	148.37	228	296
$4\frac{1}{2}$	....	21.69	44.87	79.62	113.12	158.76	239	310
5	....	23.62	48.81	83.	122.	167.25	250	324
$5\frac{1}{2}$	....	25.81	51.38	87.88	128.62	174.88	261	338
6	....	26.87	53.31	92.38	131.75	204.25	272	352
$6\frac{1}{2}$	....	.....	56.87	96.88	139.56	214.69	283	366
7	....	.....	59.12	99.87	145.50	228.44	294	370
$7\frac{1}{2}$	....	.....	61.87	105.75	150.88	235.31	305	384
8	....	.....	64.44	109.50	157.12	239.88	316	398
9	....	.....	70.50	118.12	169.62	258.12	338	426
10	....	.....	77.	128.13	184.	276.18	360	454
11	....	.....	82.88	136.19	195.13	295.69	382	482
12	....	.....	86.37	144.87	209.75	311.94	404	510
13	....	.....	92.	155.50	219.37	335.81	426	538
14	....	.....	97.75	163.58	237.50	351.88	448	566
15	....	.....	103.25	170.75	249.06	391.75	470	594

TABLE XVII.

STANDARD SIZES OF WASHERS.

(C. W. & H. W. Middleton, Philadelphia.)

Size of bolt. Inch.	Diameter of washer. Inch.	Size of hole. Inch.	Thickness, wire gauge. No.	Number in 100 lbs.
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{16}$	16	29,300
$\frac{5}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	16	18,000
$\frac{3}{8}$	1	$\frac{7}{16}$	14	7,600
$\frac{1}{2}$	$1\frac{1}{8}$	$\frac{9}{16}$	11	2,100
$\frac{9}{16}$	$1\frac{1}{2}$	$\frac{5}{8}$	11	2,180
$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{11}{16}$	11	2,350
$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{13}{16}$	11	1,680
$\frac{7}{8}$	2	$\frac{31}{32}$	10	1,140
1	$2\frac{1}{2}$	$1\frac{1}{8}$	8	580
$1\frac{1}{8}$	$2\frac{3}{4}$	$1\frac{1}{4}$	8	470
$1\frac{1}{4}$	3	$1\frac{3}{8}$	7	360
$1\frac{3}{8}$	3	$1\frac{1}{2}$	6	360

TABLE XVIII.

SHOWING NUMBER OF "BURDEN'S" RIVETS IN 100 POUNDS.

Length in inches.	½ inch diameter.	⅝ inch diameter.	11-16 inch diameter.	¾ inch diameter.
¾	1,092	665	....	....
⅞	1,027	597	....	....
1	940	538	450	....
1⅛	840	512	415	....
1¼	797	487	389	356
1⅜	760	460	370	329
1½	730	440	357	280
1⅝	711	420	340	271
1¾	693	390	325	262
1⅞	648	375	312	257
2	608	360	297	243
2⅛	573	354	289	237
2¼	555	347	280	232
2½	525	335	260	220
2¾	500	312	242	208
3	460	290	224	197
3¼	433	267	212	180
3½	413	248	201	169
3¾	395	241	192	160
4	....	230	184	158
4¼	....	220	177	150
4½	....	210	171	146
4¾	....	200	166	138
5	....	190	161	135
5¼	....	180	156	130
5½	....	172	151	124
5¾	....	164	145	120
6	....	157	140	115
6¼	....	150	138	111
6½	....	146	134	107
6¾	....	143	129	104
7	....	140	125	100

CHAPTER V.

TESTING THE MATERIALS.

1. General Character of Tests.—The tests to be applied to materials used in the construction of boilers are of three different kinds—viz., first, the investigation of the mechanical properties of the materials as developed in the testing-machine; secondly, the trial of the quality of the materials affecting their fitness to undergo the various mechanical processes employed in boiler-making; thirdly, the search for imperfections in the structure of the materials developed in the process of manufacture.

2. United States Laws and Regulations regarding the Tests of Boiler-plates.—The 'Revised Statutes of the United States' prescribe the following tests for boiler-plates: "*Section* 4430. Every iron or steel plate used in the construction of steamboat boilers, and which shall be subject to a tensile strain, shall be inspected in such manner as shall be prescribed by the Board of Supervising Inspectors and approved by the Secretary of the Treasury, so as to enable the inspectors to ascertain its tensile strength, homogeneousness, toughness, and ability to withstand the effect of repeated heating and cooling; and no iron or steel plate shall be used in the construction of such boilers which has not been inspected and approved under those rules.

"*Section* 4431. Every plate of boiler-iron or steel made for use in the construction of steamboat boilers shall be distinctly and permanently stamped by the manufacturer thereof, and, if practicable, in such places that the marks shall be left visible when such plates are worked into boilers, with the name of the manufacturer, the place where manufactured, and the number of pounds tensile strain it will bear to the sectional square inch."

'The General Rules and Regulations prescribed by the Board of Supervising Inspectors of Steam-vessels,' January, 1879, contain the following instructions regarding the tests to be applied to boiler-plates:

"*Rule* 3. Every iron or steel plate intended for the construction of boilers to be used on steam-vessels shall be stamped by the manufacturer in the following manner—viz., at the diagonal corners, at a distance of about four inches from the edges, and also at or near the centre of the plate, with the name of the manufacturer, the place where

manufactured, and the number of pounds tensile strain it will bear to the sectional square inch.

"When a sheet of boiler-iron is found by the inspector with one or more stamps upon the same, the inspector shall in every such case be governed by and rate the tensile strain of iron in accordance with the lowest stamp found upon the same.

"*Rule* 4. The manner of inspecting and testing boiler-plates intended to be used in the construction of marine boilers, by the United States inspectors, shall be as follows, viz.:

"The inspector shall visit places where marine boilers are being constructed, as often as possible, for the purpose of ascertaining and making a record of the stamps upon the material, its thickness, and other qualities. To ascertain the tensile strain [strength] of the plates the inspector shall cause a piece to be taken from each sheet to be tested, the area of which shall equal one-quarter of one square inch on all iron $\frac{5}{16}$ inch thick and under; and on all iron over $\frac{5}{16}$ inch thick the area shall equal the square of its thickness, and the force at which the piece can be parted in the direction of the fibre or grain, represented in pounds avoirdupois—the former multiplied by four, the latter in proportion to the ratio of its area—shall be deemed the tensile strain per square inch of the plate from which the sample was taken; and should the tensile strength ascertained by the test equal that marked on the plates from which the test-pieces were taken, the said plates must be allowed to be used in the construction of marine boilers, provided always that the said plates possess the other qualities required by law—viz., homogeneousness, toughness, and ability to withstand the effect of repeated heating and cooling; but should these tests prove the marks on the said plates to be overstamped, the lots from which the test-plates were taken must be rejected as failing to have the strength stamped thereon. But nothing herein shall be so construed as to prevent the manufacturers from restamping such iron at the lowest tensile strain indicated by the samples, provided such restamping is done previous to the use of the plates in the manufacture of marine boilers.

"To ascertain the ductility and other lawful qualities, iron under 45,000 pounds should show a contraction of area of 12 per cent.; 45,000 pounds and under 50,000 should show 15 per cent.; 50,000 pounds tensile strength and over should show 25 per cent. at point of rupture."

3. The Rodman Testing-machine.—The Rodman Testing-machine at the Ordnance Department of the Washington Navy-Yard has been used in making several of the experiments recorded in this volume. An illustration of it is given on Plate I. It consists essentially of a system of three levers, A, B, and C, the arms of which have

the following proportions: A = 10 : 1; B = 20 : 1; C = 10 : 1; consequently the total leverage of the machine is 2,000 : 1. The machine is capable of measuring a stress of one hundred thousand pounds, and is arranged to determine tensile, compressive, transverse, and torsional stresses, as well as indenting forces and bursting pressures applied to hollow vessels.

The main lever A acts directly upon the specimen by means of the stirrup D. The fulcrum F of the main lever is supported by a pair of heavy cast-iron stanchions, S S, secured by bolts to the bed-frame T. The stirrup D bears upon the lever A by means of the knife-edge *a*, and has at its lower end a shackle, *d*, to which the various contrivances for transmitting the stress to the specimen under test are attached. A strap, E, connects the main lever with the intermediate lever B, which, in turn, is connected by means of the adjustable rod G with the small lever C. On the latter are placed the weights producing the stress to which the specimen is to be exposed. The lever C is graduated from 0 to 10 and carries a small sliding-weight, *p;* by moving this weight one division of the scale out from the fulcrum a stress of 100 pounds is exerted on the specimen attached to the stirrup D. At the point *c*, corresponding to the tenth division, the lever C carries a rod, H, on which additional weights can be placed; of these there are two kinds—viz., ten representing a stress of 1,000 lbs. each, and nine representing a stress of 10,000 lbs. each at the point *a*.

In order to counterbalance exactly the weight of the levers and their attachments the weights V and V′ can be moved in or out on the rods passing through their centre; V being attached directly to the lever C, while V′ acts by means of a lever and strap on the intermediate lever B. In order to reduce the friction to a minimum case-hardened steel knife-edges are used for the bearings of the levers and their connections.

It is evident that any movement of the point *d* on the lever A, caused by the elongation, compression, or deflection of the specimen, is increased two-thousandfold at the point *c* of the lever C; it is, however, essential to maintain the levers in an exactly horizontal and parallel position, since otherwise the leverage of the machine would be altered, and its balance would be disturbed by shifting the centre of gravity of the levers. On this account the fulcrums *f* and *f′* of the levers B and C are attached to the sliding-blocks *g* and *g′*, which can be moved up or down by suitable gearing. The hand-crank N turns, through the intervention of a train of wheels and pinions, the horizontal wheel O, which, in turn, gives motion to the screw R, the central boss of the wheel forming a nut for the screw; the lower end of the latter is attached to the sliding-block *g*, which is guided between the frames Z Z. To this block is attached the rack *h*, gearing with a pinion fastened on the shaft J which carries, on its other end,

a corresponding pinion, i', gearing with the rack h'; the latter is attached to the sliding-block g', which is guided between brackets forming part of the stanchions S S. In this manner the vertical motion of the fulcrum f of the lever B is communicated to the fulcrum f' of the lever C, and the horizontality and perfect parallelism of the two levers can be maintained. No means are provided to keep the main lever in a horizontal position during the operation of the machine, but the error arising from this source is trifling, since this lever has always only a comparatively slight motion. In order that the disturbance of the balance of the machine in consequence of the motion of the centre of gravity of the lever A be as small as possible, the lever has received such a shape that its centre of gravity lies near its centre of motion.

The large screw U, placed directly under the point a, passes through the bed-frame and can be adjusted to a proper height by means of a hand-wheel. Its upper end is provided with a suitable arrangement for holding the specimen subjected to a tensile strain or the straps used in applying compressive and indenting forces.

When transverse strains are to be produced the two movable pedestals, X X, attached to the bed-frame are used. They are fitted with knife-edges, against which the test-bar bears, the strain being applied, by a strap connected to the stirrup D, to the lower side of the bar.

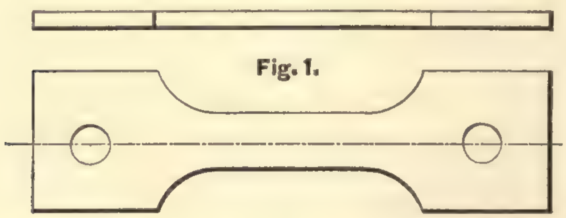
Torsional strains are measured by means of the lever M, which works between the two pillow-blocks, Y Y, secured to the bed-frame. The hollow axis of this lever receives the specimen, the projecting ends of which are firmly secured by cotters to the blocks. The lever M is connected by means of a chain and link to the intermediate lever B. A graduated arc is attached to the pillow-block Y, and a pointer connected with the axis of the lever indicates the number of degrees through which the specimen has been twisted.

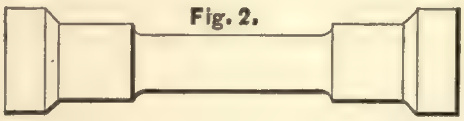
Before beginning an experiment the machine is balanced by a proper adjustment of the weights V and V′, so that the weights placed on the lever C measure accurately the stress applied to the specimen. When a specimen has been put in place to test its tensile or compressive strength care is taken that all lost motion is taken up by moving the screw U up or down, while the lever C is kept in a horizontal position. Then the hand-crank is turned with regularity in a direction which raises the screw R, and through it the fulcrums f and f', while at the same time the sliding-weight p is moved so as to keep the lever C in an exactly horizontal position. Whenever the sliding-weight p registers a strain of 1,000 lbs., one of the large weights, P, representing an equivalent strain, is substituted for it on the rod H, and the sliding-weight is moved back to the zero-point. In the same manner a weight, P′, representing a strain

of 10,000 lbs., is placed on the rod H in the place of ten weights of 1,000 lbs. each. By repeating these operations the effects of increments of 100 lbs. each, up to the limit of 100,000 lbs., can be observed and measured.

4. Form and Dimensions of Test-specimens.—The sectional area of specimens that are to be tested is limited by the strength of the machine. It is very convenient to give such dimensions to the specimen that its sectional area is a simple multiple or fraction of a square inch.

It is found that long bars generally stretch more, in proportion to their length, than short ones of the same material, sectional area, and form. In order to secure greater uniformity in the conditions of tests the French Government established the rule that the length of all specimens subjected to tests of tensile strength should be 200 millimetres (7.875 inches) between the shoulders; and, following this precedent, the English Admiralty has adopted a standard length of 8 inches.





Figures 1 and 2 show the forms usually given to specimens. The middle portion, which is the part to be tested, must be carefully turned or planed, as the case may be, to the exact dimensions required, so as to have the sides perfectly parallel. It is essential that the strain be applied exactly in the direction of the axis of the specimen. In order to measure the elongation of the specimen under strain its length is divided by lines or centre-punch marks into equal spaces. Kirkaldy described on the surface of some specimens a network of diagonal lines or circles, the distortion of which represented the relative elongation of different portions of the specimen. Specimens of very thin plates may have side-plates riveted to their ends to give them longer bearings on the pins of the shackles. Specimens subjected to a crushing strain are seldom made longer than twice their diameter.

The influence of length and form on the apparent strength of test-specimens is illustrated by "the results of a series of trials of samples of steel cut from the same plate and reduced in width as shown" (see figures 3 and 4), given by Reed in 'Shipbuilding in Iron and Steel,' pp. 401, 402. "Eight cases were taken, each case being tested by three experiments for each mode of reduction. The breaking section was in each case

reduced to a breadth of one inch, the reduction from the extreme breadth of the samples (2¼ inches) being made in one set of plates by circular arcs, and in the other

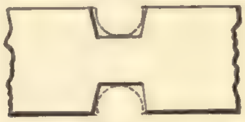


Fig. 3.

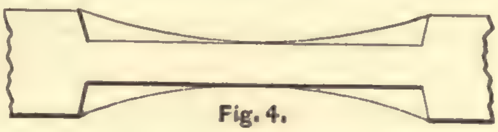


Fig. 4.

set by parallel reductions. The lengths of the reduced parts were varied from 8 inches to 1 inch by successive deductions of 1 inch, and the sketches (figures 3 and 4) show the extreme cases of the longest and shortest reductions respectively. The forms of the circular arcs are shown in ticked lines, and those of the parallel reduction by drawn lines." . . . "Throughout these experiments, which were conducted with extreme care, the same material broke at a less strain when trimmed down to a parallel breadth for a considerable distance than when reduced to the same breadth at one place only. By comparing the samples reduced to a parallel breadth for a length of 8 inches with those similarly rèduced for a length of 1 inch only, it will be seen that the apparent strength rose from an average of 19¼ tons to an average of 21¾ tons; or if we compare the former with the case of the shortest circular reduction, we find it increasing from 19¼ tons to an average of 23¾ tons."

Numerous experiments were also made by the United States Test Board to determine the proper form and dimensions of test-pieces. The results of these experiments are summed up in the report of the Board in the following words: "In conclusion, our results lead us to the decision that in testing [wrought] iron no test-piece should be less than ½ inch diameter, as inaccuracy is more probable with a small than with a large piece, and the errors are more increased by reduction to the square inch; that the length should not be less than four times the diameter in any case, and that with soft, ductile metal five or six diameters would be preferable."

In preparing the specimens care must be taken that the metal does not receive injury impairing its strength. On this account they should be cut from the plate by sawing or drilling, and then filed down to the exact dimensions. In case punching is resorted to it is necessary to leave a surplus of metal for planing or filing down, in order that the specimen may not be weakened by the injury which the metal receives in the vicinity of a punched hole.

5. Effects produced by Stress.—Under a gradually increasing tensile stress the elongation of metals may be assumed to be in the direct ratio of the stress, within the limit of elasticity, and whenever the stress is discontinued the specimen will resume

very nearly its original dimensions. The elongation of wrought-iron is about $\frac{1}{10000}$ part of its length for every ton of tensile stress per square inch of sectional area, and its limit of elasticity lies between 8 and 12 tons of tensile strain per square inch. A bar which has been strained beyond the limit of elasticity, and has in consequence taken a permanent set after the stress had been removed, will show a much smaller rate of elongation for all stresses less than that which produced the set.

Anderson says: "A bar of wrought-iron, when it leaves the rolls, is in a condition of great restraint; the exterior is not in perfect equilibrium with the interior of the bar, which at the commencement of an experiment affects the elongation and permanent set. The first effect of the application of a load is to liberate the constrained surface, and true conditions on which to form an opinion do not exist until equilibrium is established in the bar itself. Previous to that the result is deceptive; hence the advantage of carefully-turned specimens."

Soft and ductile materials are drawn out to a much smaller diameter at and near the point of fracture before the final rupture takes place. Kirkaldy was the first to point out the importance of calculating the ultimate breaking stress per square inch for the contracted area at the point of fracture as a measure of the quality of the material.

Fibrous wrought-iron is stronger and stretches more in the direction of the fibres than across them; hence the importance of cutting test-specimens of boiler-plate in both directions from the sheet.

The molecular changes of a ductile material, when strained, may be compared to those occurring during the flow of liquids.

Anderson says: "When a bar is drawn out the principal flow of the apparently solid metal is in the middle of the stream, and hence the peculiar sectional form which is assumed either by a round or square bar, or one of any other shape, showing that the farther the molecules of the material are removed from the centre of the flowing current, so much the less are they affected by the influence of the general movement. This unequal flowing of the molecules may partly account for the apparent weakness of thin plates as compared with round bars of the same sectional area."

"With a flowing, malleable, or ductile metal the round bar, when under tension, is drawn out to a small diameter uniformly all around, but the metal goes in the middle chiefly, and the outside is shrivelled; while with a rectangular or square bar the flat surfaces are slightly hollowed to an extent proportionate to their distances from the centre of the flow."

6. Experiments on the Effects of Hammering and Rolling on the Strength of Bars.—"Early in the course of the mechanical tests [of the United States

Test Board] it became evident that, although each set of nine bars (1 inch to 2 inches diameter) from any maker was made of the same material and as uniformly as ordinary processes would allow, yet there was a notable variation in the physical characteristics of the different-sized bars. The tenacity, elastic limit, and ductility increased as the diameter decreased. In fourteen sets of bars the strength per square inch of the 1-inch over the 2-inch ran from 4,000 to 7,000 lbs.; and in bars known to have had uniform treatment it averaged 5,600 lbs. But the increase of strength was not uniform. In eight sets of bars the strength fell off at the 1½-inch size.

"An investigation of the method of manufacture revealed the causes of these phenomena. The piles from which the 2-inch, 1⅞-inch, 1¾-inch, and 1⅝-inch bars were rolled had the same cross-section, differing only in length. The piles from the 1½-inch, 1⅜-inch, 1¼-inch, and 1⅛-inch, and sometimes the 1-inch, were of the same area, although smaller than the piles above mentioned. The areas of the piles remaining constant with each set, while those of the bars decreased, the smaller bars received the most work in the rolls. It was then found by numerous experiments that the tenacity and elastic limit of the various bars of a set increased just in proportion to the decrease of the percentage of the area of the bar to that of the pile.

TABLE XIX.

Size of bar.	Iron *N*, showing decrease of strength by decrease of reduction.			Iron *Fx*, showing uniformity of strength with uniformity of reduction.		
	Area of bar in per cent. of area of pile.	Tensile strength.	Elastic limit.	Area of bar in per cent. of area of pile.	Tensile strength.	Elastic limit.
Inches.	Per cent.	Pounds per square inch.	Pounds per square inch.	Per cent.	Pounds per square inch.	Pounds per square inch.
	(Pile 6″ × 4⅜″.)					
2	11.36	51,848	32,461	3.92	50,763	33,258
1⅞	10.22	54,034	33,610	3.45	53,361	35,032
1¾	8.90	55,018	34,283	3.34	53,154	35,323
1⅝	7.68	56,344	35,889	3.24	53,329	33,520
	(Pile 4″ × 3⅜″.)					
1½	11.78	53,550	34,690	3.27	52,819	34,840
1⅜	9.90	54,277	33,622	3.53	52,733	34,606
1¼	8.18	56,478	33,251	3.41	53,248	33,520
1⅛	6.62	56,543	32,267	3.31	54,645	34,695
1	....	....	....	3.14	53,915	36,287

"In order to determine if the converse is true another set of experiments was undertaken, and it proved that, by preserving a uniform proportion of bar to pile, all the bars of the series have substantially the same strength per square inch.

"Table XIX. gives two typical examples, selected from the records of the Board. That of iron *N* shows the effect of variation in the percentages of pile to bar; that of iron *Fx* the effect of uniformity." (*A. L. Holley*, '*The Strength of Wrought-iron as affected by its Composition and by its Reduction in Rolling.*')

In the Report of the Committee on Chain-cables, Malleable Iron, etc., of the United States Test Board, it is stated that, although the strength of the entire bar was increased by the extra work in rolling the bar from a larger pile, yet that of the core of the iron was not, as shown by the following tests:

TENSILE STRENGTH AND ELASTIC LIMIT OF THREE BARS, IRON *Fx*, AS FOUND BY RUPTURE OF ENTIRE BARS AND OF TURNED CYLINDERS.

Size. Inches.	Area of entire bars in per cent. of area of piles.	Tensile strength.		Elastic limit.	
		Entire bar. Pounds per sq. inch.	Cylinder. Pounds per sq. inch.	Entire bar. Pounds per sq. inch.	Cylinder. Pounds per sq. inch.
2	3.93	52,011	45,964	34,702	31,830
$1\frac{5}{8}$	3.45	53,537	47,124	34,235	32,070
1	2.62	55,770	49,656	34,279	35,714

Plate II. contains the record of experiments conducted by Chief-Engineer Wm. H. Shock, U. S. N., which are instructive in showing the effect of an increased amount of hammering and rolling on the tenacity and ductility of a bar of wrought-iron.

The test-specimens were all cut from the same bar, which was of good marketable American iron, 4 inches square. One end of the bar was drawn down by hammering to a size of $2\frac{1}{4}$ inches square. The diagrams on Plate II. show from which particular portion of the bar each specimen was cut. The specimens were carefully turned to the exact size given on the plate, and were subjected to a tensile strain in the Rodman Testing-machine represented on Plate I.

Comparing the results obtained with specimens cut from different portions of the bar, we find: *First*, that the mean tensile strength of the eight specimens marked E, which were cut from the sides of the bar, was 2.13 per cent. greater than that of the four specimens marked D, which were cut from the centre of the bar; and that the mean elongation of the former was 16.1 per cent. greater than that of the latter. *Secondly*,

that the mean tensile strength of the six specimens marked A, which were cut from the reduced end of the bar, was 5.63 per cent. greater than that of the specimens marked D; and that the mean elongation of the former was 9.79 per cent. greater than that of the latter. *Thirdly*, that the mean tensile strength of the eight specimens marked B and C, which were cut across the fibre of the bar, was 40.85 per cent. less than that of the specimens marked D; and that they broke without showing any elongation. *Fourthly*, that the several specimens marked B and C broke under widely different strains: the lowest result obtained (specimen B1) was 33.73 per cent. less than the mean result obtained with the eight specimens of classes B and C; and the highest result obtained (specimen B2) was 35.51 per cent. greater than the mean result. Specimens B1 and B2 were cut from immediately adjoining portions of the bar. The highest and lowest breaking strains obtained with specimens of class D differ less than one per cent. from the mean result; and with specimens of class E this difference is only a fraction more than one per cent. The difference of the results obtained with specimens of class A is equally slight, with the exception of specimen A6, which broke under a strain 4.08 per cent. higher than the mean breaking strain of class A. The portion of the bar from which A6 was cut had probably received a greater amount of hammering at a lower temperature; this assumption appears to be confirmed by the smaller amount of elongation of this specimen before rupture occurred.

7. Appearance of Fractures.—The fracture of iron and steel should present a close, uniform grain of a bright gray color, or a silky fibre; when of a dull, earthy aspect, with a loose texture, an unequal grain, or a blackish fibre, it indicates an inferior quality or a badly-refined material.

Fractures of steel may be classified as granular, crystalline, and fibrous, and those of wrought-iron as crystalline and fibrous, with intermediate gradations. Hard, unyielding materials always present a granular or crystalline fracture.

With respect to wrought-iron Kirkaldy deduces the following results from his experiments: "1st. Whenever wrought-iron breaks *suddenly* a *crystalline* appearance is the invariable result; when *gradually*, invariably a *fibrous* appearance. 2d. Whether, on the one hand, it is finely or coarsely crystalline, or, on the other, the fibre be fine or close, or coarse and open, depends upon the quality of the iron. 3d. When there is a combination in the same bar or plate of two kinds—the one harder or less ductile than the other—the appearance will be partly crystalline and partly fibrous. . . . 5th. The relative qualities of various irons may be pretty accurately judged of by comparing their fractures, provided they have all been treated in precisely the same way, and all broken under the same sort of strains similarly applied. 6th. By varying either the

shape, the treatment, the kind of strain, or its application, pieces cut off the same bar will be made to present vastly different appearances in some kinds of iron, whilst in others little or no difference will result. . . .

"The appearance of the same bar may be completely changed from wholly fibrous to wholly crystalline, . . . 1st, by altering the shape of the specimen so as to render it more liable to snap ; 2d, by treatment making it harder ; and, 3d, by applying the strain so suddenly as to render it more liable to snap from having less time to stretch. . . .

"In the case of the fibrous fracture the threads are drawn out and are viewed *externally ;* in the case of the crystalline fracture the threads in clusters are snapped across, and are viewed *internally* or *sectionally*. . . .

"The conclusions respecting wrought-iron are equally appropriate to steel—viz.: Whenever rupture occurs *slowly* a silky fibrous, and when *suddenly* a granular, appearance are invariably the result ; both kinds varying in fineness according to quality. The surface in the latter case is even, and always at right angles with the length ; in the former angular and irregular in outline. The color is a light pearl gray, slightly varying in shade with the quality ; the granular fractures are almost entirely free of lustre, and consequently totally unlike the brilliant crystalline appearance of wrought-iron."

8. Hot and Cold Forge-tests.—The forge-tests applied to boiler-plates used in the United States naval service vary according to the judgment of the superintending or inspecting officers. The specifications generally require that the plates must be able to bear the severest flanging-tests to which they may be subjected. These consist in turning flanges on two adjacent sides of a plate, thus forming a corner ; in cutting a hole in the middle of a plate and enlarging it by turning a flange up around it ; in giving a dished shape to the plate by forcing it, by means of a jack and a spherical die, into a corresponding form. The plates are further tested cold by punching holes near the edges, and by bending them to angles of different degrees, according to the thickness of the plates. They must bear these several tests without showing any signs of cracks or laminations.

In the English service the iron supplied by the manufacturers has to undergo the tests described in section 11, chapter vii., which are carried out in the same manner, as nearly as possible, in the various establishments, both private and public, under the supervision of Admiralty officers. In applying the bending-tests it is prescribed that plates, both hot and cold, should be tested on a cast-iron slab, having a fair surface, with an edge at right angles, the corner being rounded off with a radius of $\frac{1}{2}$ inch. The plate should be bent at a distance of from 3 to 6 inches from the edge.

Wilson says: "All plates of the very best quality, having a longitudinal tenacity of 24 tons per square inch of section and an ultimate elongation of about 12 per cent., and not exceeding one inch in thickness, should bend double along or across the fibre when red-hot.

"For the cold forge-test plates of the very best quality $\frac{7}{16}$ inch thick and under should bend double without fracture. . . .

"The angle to which the plates can be bent without fracture will depend greatly upon the skill of the smith who heats and operates upon them. A plate that will bear the test with a number of sharp, light blows will often fail when a heavy hammer is used. By striking the plate along its surface it can be successfully bent to a much greater angle than when the blows are dealt perpendicularly to the surface.

"The plate will also stand the bending much better if it is performed uniformly along its whole width. . . . The manner in which a plate will bear flanging outwardly, whereby the fibres are either stretched or separated, as the plate is flanged across or along the grain, is generally considered the best test of its soundness and quality. . . .

"Rivets and bars for boiler-work are seldom tested for their tensile strength, but their quality is usually ascertained by the forge-tests. A good rivet, cold, will bend double without fracture. The head of a good rivet should flatten out, by hammering when hot, to about $\frac{1}{8}''$ thick, without fracture or fraying at the edge. A hot rivet-shank or bar of iron, when flattened down to a thickness equal to about one-half its diameter, should bear a punch driven through it without fracture at the hole."

9. Directions for testing Bar-iron.—"Cut a notch on one side with a cold-chisel, then bend the bar over the edge of an anvil at sharp angles. If the fracture exhibits long, silky fibres of a leaden gray color, cohering together, and twisting or pulling apart before breaking, it denotes tough, soft iron, easy to work and hard to break. In general a short, blackish fibre indicates iron badly refined. A very fine, close grain denotes a hard, steely iron, which is apt to be cold-short, but working easily when heated, and making a good weld. Numerous cracks on the edges of the bar generally indicate a hot-short iron, which cracks or breaks when punched or worked at a red heat, and will not weld. Blisters, flaws, and cinder-holes are caused by imperfect welding at a low heat, or by iron not being properly worked, and do not always indicate inferior quality.

"To test iron when hot, draw a piece out, bend and twist it, split it, and turn back the two parts to see if the split extends up; finally weld it, and observe if cracks or flaws weld easily. Good iron is frequently injured by being unskilfully worked;

defects caused by this may be in part remedied. If, for example, it has been injured by cold-hammering moderate annealing heat will restore it." (*King.*)

10. Testing Steel Boiler-plates.—For steel boiler-plates the following tests are prescribed by the French Government: "*Hot tests:* These tests will be made with sample plates of suitable dimensions, and consist in stamping a dished cavity, the side of the plates preserving its original plane. The diameter of this cavity is to be equal to forty times the thickness of the plate, and the depth will be ten times this thickness; the flat edge to be joined to the cavity by a curve the radius of which is not to be greater than the thickness of the plate. Moreover, plates more than .197 inch will be stamped with a flat-bottomed depression with square angles and straight sides, the diameter of the bottom to be thirty times the thickness of the plate, and the depth ten times the same thickness. The bottom of this cavity will be pierced with a round hole, with the metal forced perpendicularly beyond the bottom of the recess; the diameter of the hole to be twenty times the thickness of the plate, and the height of the sides five times the same thickness. All the corners will be rounded with a curve not of greater radius than the thickness of the plate. The pieces thus tested, with every precaution which the working of steel requires, must show no signs of yielding or cracking, even when cooled in a brisk current of air.

"*Tempering tests:* For these tests bars 10.24 inches long by 1.58 inches wide will be cut from the plate longitudinally as well as transversely. These strips will be heated uniformly to a slightly dull cherry-red, and then tempered in water at a temperature of 82° Fahr. Thus treated they must be bent in the testing-machine to a curve of which the minimum radius is not greater than the thickness of the bars. These same bars, when the corresponding plates are to be used for boilers, will be bent double in the press without showing any traces of fracture, and in such a way that the halves of the plate may be in contact. The sides of the bars thus tested, if round, can be squared up with a file. Plates not coming up to these tests will be rejected."

11. Tests for Plate, Beam, Angle, Bulb, and Bar Steel used in building Ships for Her Majesty's Navy.—*Admiralty*, 9th January, 1879. (The same directions are followed for steel used for boiler-shells.)

"Strips cut lengthwise or crosswise to have an ultimate tensile strength of not less than 26, and not exceeding 30, tons per square inch of section, with an elongation of 20 per cent. in a length of 8 inches. The beam, angle, bulb, and bar steel to stand such forge-tests, both hot and cold, as may be sufficient, in the opinion of the receiving officer, to prove soundness of material and fitness for the service.

"Strips cut crosswise or lengthwise $1\frac{1}{2}$ inches wide, heated uniformly to a low cherry-

red and cooled in water of 82° Fahr., must stand bending in a press to a curve of which the inner radius is one and a half times the thickness of the steel tested.

"The strips are all to be cut in a planing-machine, and to have the sharp edges taken off.

"The ductility of every plate, beam, angle, etc., is to be ascertained by the application of one or both of these tests to the shearings, or by bending them cold by the hammer.

"All steel to be free from lamination and injurious surface-defects.

"One plate, beam, or angle, etc., to be taken for testing from every invoice, provided the number of plates, beams, or angles, etc., does not exceed fifty. If above that number, one for every additional fifty or portion of fifty. Steel may be received or rejected without a trial of every thickness on the invoice.

"The pieces of plate, beam, or angle, etc., cut out for testing are to be of parallel width from end to end, or for at least eight inches of length.

"Plates may be ordered either by weight per superficial foot or by thickness. In the former case the weight named will always be the greatest that will be allowed, and a latitude of 5 per cent. below this will be allowed for rolling in plates of ½ inch in thickness and upwards, and 10 per cent. in thinner plates. When the plates are ordered by thickness their weight is to be estimated at the rate of 40 pounds per square foot for plates of one inch thick, and in proportion for plates of all other thicknesses. In this case, also, the weight due to the thickness by this calculation is not to be exceeded, but the same latitude as above will be allowed below the weight for rolling. The average weight per foot of the plates ordered is to be ascertained by weighing not less than 10 tons at a time when larger parcels than 10 tons are delivered; if these 10 tons exceed the due weight (calculated as stated above), or are more than the before-mentioned percentage below it, the whole may be rejected. In smaller deliveries than 10 tons the average is to be ascertained by weighing the whole parcel. The same conditions as to latitude and mode of ascertaining weight apply also to other descriptions of steel in the contract."

12. Examining Boiler-plates.—The method pursued in the English dockyards for examining iron plates as to imperfections developed in the process of manufacture is described by Reed as follows: "When parcels or lots of iron plates are delivered into the building-yard they are spread out and examined with the object of first ascertaining if the manufacturer's name and the brand of quality are duly stamped upon each plate, and then of searching for surface-defects, such as blisters, flaws, laminations, or bad places caused by dirt or cinders getting between the rolls during the

rolling of the plates, any one of which, if considerable, would cause the overseer to reject the plate. This surface-examination being completed, each plate is raised from the ground, and, being either hung by one edge or otherwise suitably supported, is tapped over with a small hammer. If it everywhere gives out a clear, ringing sound the plate is considered to be solid; but if a heavy and dull sound be given out it is presumed that the plate is laminated or otherwise defective. If this test is audibly decisive against the plate it is at once rejected; but if the quality of the plate appears doubtful a further test is resorted to. This consists in supporting the plate at its four corners, strewing the upper surface with sand, and lightly tapping over the under side. Wherever the plate is sound the sand will be driven up off the plate by each tap of the hammer, but if it is blistered or laminated at any place the sand will not there be moved. The plates which the foregoing tests show to be satisfactory are next carefully measured and weighed, their actual weights being compared with those due to their dimensions and specified thickness."

It is convenient to mark the plate off with a chalked line into squares of four or six inches to make sure that each part of the plate is tapped with the hammer; a few blows in each square will be sufficient. Both sides of the plate should be thus tested; sometimes a plate will appear to be quite sound on one side, but will, nevertheless, be found defective on the other side.

All these tests may, however, fail to reveal internal defects, which may become apparent as soon as the plate is heated at the forge, or perhaps not until it has been for some time in use in the boiler.

CHAPTER VI.

PRINCIPLES OF THE STRENGTH OF BOILERS.

1. Resistance of Spherical Shells to an Internal Fluid Pressure.—An elastic fluid contained in a closed vessel presses each unit of area of the surrounding walls with equal force. The resistance offered by the walls depends on their superficial area, their form, their thickness, and the coefficient of resistance of the material.

The hollow sphere encloses the largest space in proportion to the superficial area of its shell, and all vessels that are not spherical, exposed to an internal fluid pressure, experience distortion on account of their tendency to assume the spherical form. A hollow sphere, having a shell of uniform thickness composed of a homogeneous material, experiences the same tension at all sections of metal formed by diametrical planes.

The area of a diametrical section, S, of a thin spherical shell is very nearly given by formula:

$$S = 2\pi r t,$$

when t represents the thickness, and

$r =$ the inner radius of the shell,

and t is supposed to be very small compared with r.

The whole force, F, to be resisted by the tenacity of section S is equal to the excess of the internal fluid pressure per unit of area over the external pressure, into the area of the plane passing through this section, or

$$F = \pi r^2 p.$$

Assuming that every portion of section S is equally strained by F, and designating by k the coefficient of the ultimate tenacity of the material of which the shell is composed, the bursting pressure will be found from the equation: $\pi r^2 p = 2 \pi r t k$; hence

$$p = \frac{2 t k}{r}, \quad \text{[I.]}$$

and the proper ratio of the thickness to the radius of a thin hollow sphere is given by the formula:

$$\frac{t}{r} = \frac{p}{2 k}.$$

It is to be borne in mind that this proportion applies to all spherical segments.

The assumption that all portions of the section S are equally strained by an internal fluid pressure is not strictly correct, but comes sufficiently near the truth in the case of thin shells of such dimensions as are generally used in connection with steam boilers. Considering the shell to be composed of a number of concentric layers, the tension experienced by each will decrease with its distance from the centre, on account of the different ratios in which the surface and the mass of a sphere increase with an increase of radius.

2. Resistance of Cylindrical Shells to an Internal Fluid Pressure.—The tension produced in a cylindrical shell by an internal fluid pressure may be considered as being of two different kinds—viz., *first*, a tension acting in a longitudinal direction, tending to pull the ends of the cylinder apart; and, *secondly*, a tension acting in a diametrical direction, tending to split the cylinder from end to end.

The force, F, producing the first-named tension is represented by the formula:

$$F = r^2 \pi p;$$

and the sectional area, S, of a thin shell resisting this force may be represented with sufficient accuracy, as in the case of thin spherical shells, by the formula:

$$S = 2 \pi r t.$$

The value of p, when it becomes the bursting pressure, is found from the equation,

$$r^2 \pi p = 2 \pi r t k;$$

$$\text{hence } p = \frac{2tk}{r}. \quad [\text{II.}]$$

It follows that the strength of a cylindrical shell in resisting a bursting stress applied in a longitudinal direction is the same as that of a spherical shell of equal radius and thickness.

To find the value of p which would split the cylinder from end to end, let the shell be considered as divided lengthwise into rings, of which the length is unity. The force tending to rupture such a ring at the sections formed by any diametrical plane is given by formula:

$$F = 2 r p,$$

and the area of these sections by

$$S = 2 t.$$

The bursting pressure is, therefore, found from the equation:

$$2\,r\,p = 2\,t\,k;$$

$$\text{hence } p = \frac{t\,k}{r}. \quad \text{[III.]}$$

The value of p as found by equation [III.] is only half as great as the value found by equation [II.]; hence the tendency of a thin cylindrical shell to split from end to end under an internal fluid pressure is twice as great as its tendency to rupture circumferentially.

Representing the length of the cylinder by l, the equation between the total force F, acting in a diametrical direction, and the resistance of the sections of the whole shell formed by diametrical planes, assumes the form:

$$2\,r\,p\,l = 2\,t\,l\,k.$$

Since this equation gives the same value for p as is given by formula [III.] for a cylindrical ring of which the length is unity, it follows that the strength of hollow cylinders exposed to an internal fluid pressure is independent of their length.

Cylindrical shells would always preserve their true cylindrical form under an internal fluid pressure, if their ends were not necessarily rigidly attached, and thereby prevented from expanding equally with the rest of the shell in proportion to the elasticity of the material with each increase of pressure; on this account the middle portion expands more freely than the ends, and the cylindrical tube has a tendency to become barrel-shaped under such conditions. This effect, however, is appreciable only in the case of very soft and elastic materials, and no account need be taken of it in the case of tubes used in connection with boilers.

The foregoing remarks about thick hollow spheres apply equally to thick hollow cylinders.

The question has been raised whether cylindrical shells, when strained longitudinally and diametrically at the same time, did not offer a diminished resistance to rupture in any one direction. Direct experiments by Navier on wrought-iron spheres have, however, proved that the resistance of the metal, when the stress is applied simultaneously in all directions, is the same as when the tension acts in one direction only.

3. Resistance of Cylindrical Shells to an External Fluid Pressure.—Thin hollow cylinders exposed to an external fluid pressure never give way by direct crushing, but by collapsing; it may be assumed that, other things equal, the resistance of tubes to collapsing is greater as their form is more truly cylindrical and their shell more perfectly homogeneous.

Fairbairn has deduced the following formula from experiments made mostly on very

thin cylindrical tubes of various lengths and diameters—viz., for wrought-iron cylindrical tubes let

$l =$ the length,

$d =$ the diameter, and

$t =$ the thickness of the shell, all expressed in the same unit of measure, and let

$p =$ the collapsing pressure in pounds per unit of area; then

$$p = 9{,}672{,}000\,\frac{t^{2.19}}{l\,d}. \quad \text{[IV.]}$$

In case a tube is stiffened by T-iron rings or by flanges, l represents the distance between two such adjacent rings or flanges.

Fairbairn finds that the collapsing pressure of a flue of an elliptic form of cross-section is found approximately by substituting, in the preceding formula, for d the diameter of the osculating circle at the flattest part of the ellipse—that is, let a be the greater and b the less semi-axis of the ellipse; then we are to make

$$d = \frac{2\,a^2}{b}. \quad \text{[V.]}$$

In order to facilitate calculations by this formula the 2.19th power is given in the following table for such numbers as represent, in fractions of an inch, the thicknesses of boiler-plates most frequently used in the construction of boiler-flues:

TABLE XX.

		2.19th power of number.	Logarithm of 2.19th power.
$\frac{3}{16}$	.18750	.025578 +	.4078728 — 2
$\frac{7}{32}$	.21875	.035850 —	.5544863 — 2
$\frac{1}{4}$	.25000	.048027 +	.6814886 — 2
$\frac{9}{32}$	.28125	.062160 +	.7935126 — 2
$\frac{5}{16}$	.31250	.078293 —	.8937215 — 2
$\frac{11}{32}$	.34375	.096465 +	.9843715 — 2
$\frac{3}{8}$	.37500	.116715 —	.0671285 — 1
$\frac{13}{32}$	.40625	.139078 —	.1432575 — 1
$\frac{7}{16}$	.43750	.163584 +	.2137420 — 1
$\frac{15}{32}$	.46875	.190266 +	.2793614 — 1
$\frac{1}{2}$	.50000	.219151 +	.3407443 — 1
$\frac{17}{32}$	.53125	.250267 +	.3984046 — 1
$\frac{9}{16}$	.56250	.283641 —	.4527683 — 1
$\frac{5}{8}$	.62500	.357254 +	.5529772 — 1
$\frac{11}{16}$	.68750	.440177 —	.6436272 — 1
$\frac{3}{4}$	.75000	.532579 +	.7263842 — 1

In an article in the *Annales du Génie civil*, March, 1879, on the "Resistance of

Tubes subjected to an External Pressure," by Théodore Belpaire, an attempt has been made to deduce a new formula for the collapsing strength of tubes. The following is a brief synopsis of the contents of this paper:

A tube having a perfectly cylindrical form and a circular cross-section, and being made of a homogeneous material, would remain cylindrical under increasing pressures till the material gave way by crushing. But the circular cross-section is a form of unstable equilibrium for resisting external pressure, because a slight alteration of shape suffices to destroy the equilibrium under sufficiently great pressures. Want of homogeneity of the material has likewise a great influence on the resistance. It would be imprudent to rely under such circumstances upon the increase of resistance due to the homogeneity of the material and to the circular form, since it is impossible to know in advance to what extent they will be realized in construction. Fairbairn's formula represents the results of experiments where this increase of resistance obtained to a greater or less extent, and for this reason it does not appear to be reliable for determining the dimensions which should be given to internal flues. Such flues derive their strength mainly from the fastening of their ends, which may be considered as absolutely rigid, and sometimes from rigid rings by means of which the intermediate sections of the flues are joined together. The collapsing of a cylinder is always preceded by distortion; it is evident that collapse cannot take place when this distortion is not allowed to exceed a certain limit and the material is not unduly strained.

The writer then considers the case of a tube with ends rigidly fixed, and supposes that under an external pressure it changes its form in such a manner that its generatrix becomes the arc of a circle, the centre of which lies on a perpendicular erected in the centre of the generatrix; and, neglecting the elastic forces due to flexure or elongation of the fibres—which are very small as long as the curvature is slight—he investigates the shearing stresses; these attain their greatest value at the fixed ends.

Calling S the greatest shearing stress,

p the pressure in pounds per square inch,

t the thickness of the tube in inches,

L the length of the tube in inches,

he deduces the following approximate formula for the external pressure which a given tube can bear with a degree of safety depending on the value attributed to S—viz.:

$$p = \frac{2tS}{L}. \quad \text{[VI.]}$$

The writer deduces then a general value S from two experiments made by Fairbairn with elliptical tubes, because the uncertain and variable elements of strength due to the

cylindrical form and to homogeneity of the material do not enter here. When the factor of safety in the foregoing equation is to be four, the value of S becomes

$$S = 428{,}394\left(\frac{t}{D}\right) - 7{,}111{,}550\left(\frac{t}{D}\right)^2;$$

where t is the thickness and D the diameter, both expressed in inches.

Since externally-pressed tubes always derive a large increase of strength from their circular form, a factor of safety of four is considered sufficient in using these formulas.

Applying these formulas to 34 cases where tubes collapsed either in an experimental apparatus or during actual use in a steam boiler, the factor is found to vary actually from 4.2 to 16.8. With reference to those cases where the factor of safety exceeded four greatly, the writer claims that the high pressures necessary to produce collapse indicate merely the great increase of strength derived in the particular instances from the uncertain element of circular form.

A greater number of experiments are required from which to deduce an expression for S, so that the influence of thickness and diameter of the tube, and of the eccentricity of its elliptical cross-section, on the value of S may be fully determined.

For the purpose of applying the foregoing formulas in practice the following table has been calculated, giving the values of S for different values of $\frac{t}{D}$ and for different factors of safety:

TABLE XXI.

Values of $\frac{t}{D}$	Values of S for a factor of safety of			Values of $\frac{t}{D}$	Values of S for a factor of safety of		
	4	5	6		4	5	6
0.003	1221	1526	1832	0.012	4117	5146	6175
0.004	1600	2000	2400	0.013	4367	5459	6550
0.005	1964	2455	2946	0.014	4604	5755	6906
0.006	2314	2892	3471	0.015	4826	6032	7239
0.007	2650	3312	3975	0.016	5034	6292	7551
0.008	2972	3715	4458	0.017	5227	6534	7840
0.009	3280	4100	4920	0.018	5407	6759	8110
0.010	3573	4466	5360	0.019	5572	6965	8358
0.011	3852	4815	5778	0.020	5723	7154	8585

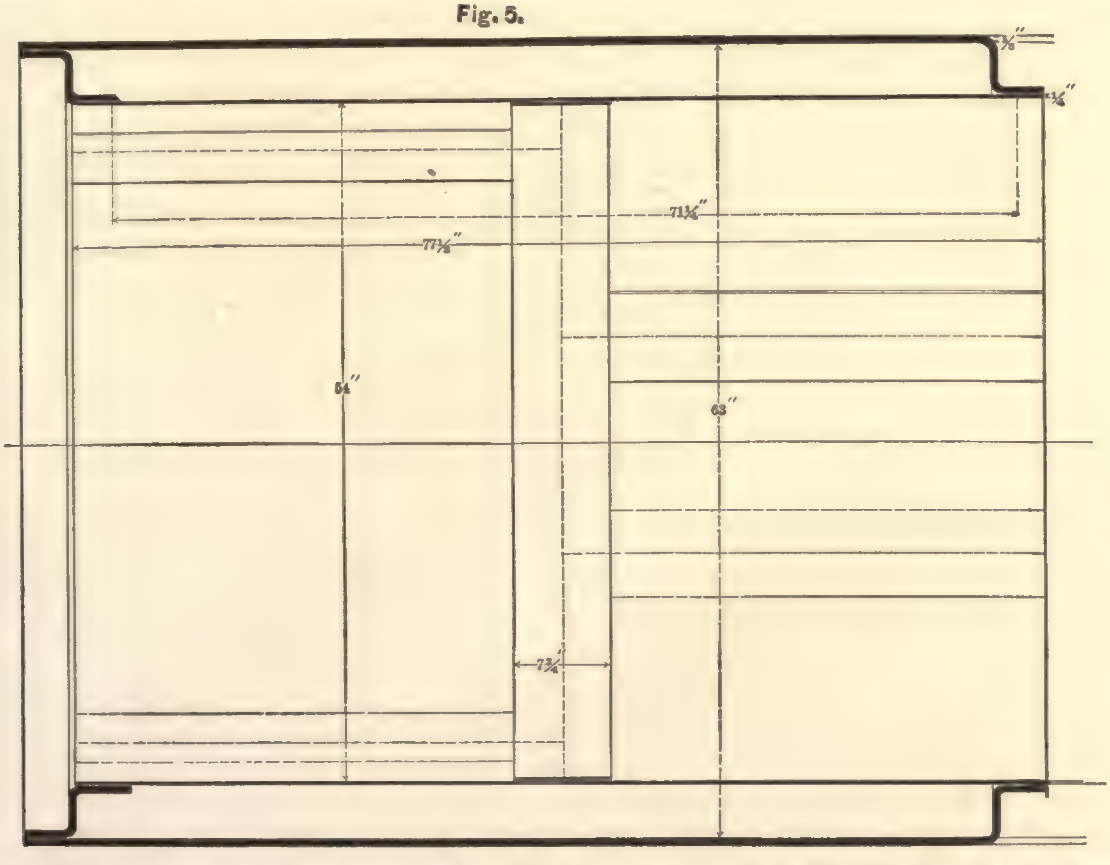
Professor Grashof has derived from Fairbairn's experiments the following empirical formula—viz.:

$$p = 1{,}057{,}180\,\frac{t^{2.061}}{l^{0.564}\,d^{0.889}}$$

In which d = diameter of the tube in inches;
l = length of the tube in inches;
t = thickness of the tube in inches;
p = pressure in pounds per square inch.

4. Experiments made on the Resistance of Cylindrical Flues to an External Fluid Pressure.—In the year 1874 experiments were made at the Washington Navy-Yard to determine the resistance of large cylindrical boiler-flues to collapse. The apparatus used for this purpose is represented in figure 5.

Fig. 5.



It consisted of a cylindrical shell of 63 inches diameter, constructed of boiler-iron ⅜ inch thick. A cylindrical flue, 77½ inches long and 54 inches in inside diameter, was securely riveted to flanges within this shell. This inner cylindrical flue was constructed of ¼-inch boiler-iron, and consisted of two rings connected by an interior butt-strap 7¾ inches wide and ¼ inch thick. Each ring was formed of two plates with butt-joints, the butt-straps, 7¾ inches wide and ¼ inch thick, being placed on the inside.

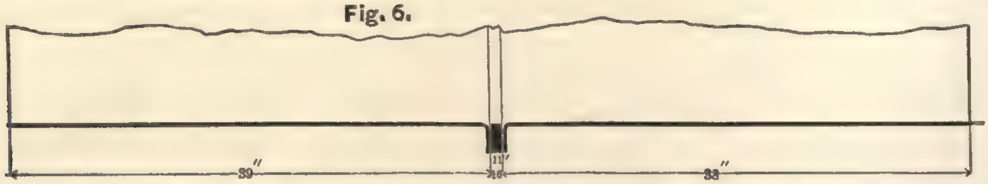
The longitudinal seams of the rings broke joint as shown in the drawing. All seams were double-riveted and carefully calked. The unsupported length of the internal flue (measured between the inner edges of rivet-holes) was $71\frac{1}{4}$ inches. A $2\frac{1}{2}$-inch pipe screwed into the outer shell connected with a force-pump, by means of which a hydrostatic pressure was produced during the trials within the annular space formed by the two cylinders. Carefully-tested spring-gauges indicated the pressure. One of the rings of the inner shell collapsed under a pressure applied to try the tightness of the joints and rivets, the two gauges used indicating a pressure of 100 lbs. and 110 lbs. respectively. The mean of these two readings was probably the true pressure, as, on comparison with a standard gauge, the one gauge was found to indicate less and the other more than the true reading near that pressure. The bulged portion of the shell of the flue was pressed out and shored up from the opposite side of the flue, and the pressure was again applied. This time collapse took place in the other ring; then the operation of forcing out and shoring up was repeated. It is evident that by this shoring up the flue became stiffer each time, and the results of the successive trials indicate this. The following are the results of the tests made with this flue:

1st	collapsed	in testing joints and rivets, at	105 lbs.
2d	"	with one bulge shored up, at	120 "
3d	"	with two bulges shored up, at	148 "
4th	"	with three bulges shored up, at	155 "
5th	"	with four bulges shored up, at	186 "

Careful measurement after construction had revealed the fact that the flue was slightly oval, the larger diameter being $54\frac{1}{4}$ inches and the smaller diameter $53\frac{3}{4}$ inches; and on removing the shell and gauging the sheets composing the flue, the one which had collapsed first was found to be slightly less in thickness than $\frac{1}{4}$ inch.

Another flue of $\frac{1}{4}$-inch boiler-iron was made, care being taken to gauge the sheets accurately before fitting them. This flue consisted likewise of two courses, 38 inches and 39 inches long respectively, but they were connected by flanges, with a ring $\frac{11}{16}$ inch thick between them (see figure 6).

Fig. 6.



This flue was found to be perfectly cylindrical, having an internal diameter of exactly 54 inches.

Three spring-gauges, that had been carefully compared with a standard gauge, were used to measure the pressure. After the first trial the bulged portion of one course was shored up as before described, and a second trial made, when the other course collapsed.

	First trial.	Second trial.
Ashcroft's gauge	132 lbs.	130 lbs.
Post's gauge	134 "	131 "
Utica gauge	134 "	131 "

Applying to the first experimental flue Fairbairn's formula, modified for elliptical tubes, viz., $p = 9{,}672{,}000 \frac{t^{2.19}}{2\,a^2} \frac{b}{l}$, we get for the collapsing pressure $p = 118.42$ lbs. This result shows a close agreement with the first two results of the experiment, when the reduced thickness of one of the sheets is taken into consideration.

The collapsing pressure of the second flue should have been nearly 240 lbs. according to Fairbairn's formula, and 225 lbs. according to Grashof's formula.

Belpaire's formula gives for the collapsing pressure of the second flue 101.2 lbs. per square inch; the actual higher collapsing pressure indicating the increase of strength due to the circular form.

5. Strength of Flat Plates.—The theory of flexure for loaded flat plates leads to very complicated expressions. The following approximate method is employed by Weisbach ('Manual of the Mechanics of Engineering,' vol. ii.) for finding the thickness of such plates:

Let m = the length, and n = the width of a rectangular flat plate secured at the circumference to a solid frame or by a row of rivets, and p = the pressure which it has to sustain per unit of surface. Let us imagine this sheet to be cut into parallel strips in the direction of the length, the ends of which are secured to the frame; and let us assume that the portion p_1 of the pressure p causes the tension of these strips; then, if we indicate the breadth of each strip by b, the thickness by t, and the coefficient of resistance to rupture by k, we have the equation:

$$m\,b\,p_1 = 2\frac{b\,t^2}{m}k,$$

or

$$m^2 p_1 = 2\,t^2 k;$$

hence

$$t = m\sqrt{\frac{p_1}{2\,k}}. \quad \text{[VII.]}$$

If, on the other hand, we imagine the plate cut up into similar strips in the direction

of its breadth, and assume that the tension of these strips is caused by the pressure $p_2 = p - p_1$, we find in the same manner

$$t = n\sqrt{\frac{p_2}{2\,k}}. \quad \text{[VII.}a\text{]}$$

As the deflection in the first case decreases as $\frac{m^4\,p_1}{t^3}$, and in the other case as $\frac{n^4\,p_2}{t^3}$, and as it is as great in the one case as in the other, we can put

$$m^4\,p_1 = n^4\,p_2;$$

hence $\qquad p_2 = \frac{m^4}{n^4}\,p_1 \qquad$ and $\qquad p = p\,\left(1 + \frac{m^4}{n^4}\right);$

consequently $\qquad p_1 = \frac{n^4\,p}{m^4 + n^4}.$

By introducing these values of p_1 and p_2 into equations [VII.] and [VII.a] we get for the thickness of the plate in the first case

$$t = n\sqrt{\frac{m^2\,n^2}{m^4 + n^4}\cdot\frac{p}{2\,k}}, \quad \text{[VIII.]}$$

and in the second case

$$t = m\sqrt{\frac{m^2\,n^2}{m^4 + n^4}\cdot\frac{p}{2\,k}}. \quad \text{[VIII.}a\text{]}$$

If $n > m$, we must find the thickness of the plate according to formula [VIII.]; if $m > n$, we must use formula [VIII.a].

For square sheets we have $m = n$, therefore

$$t = \frac{n}{2}\sqrt{\frac{p}{k}}. \quad \text{[IX.]}$$

The following formulas are given by Rankine for calculating the strength of unstayed flat surfaces secured at the edges, in which p, t, r, and k denote the same quantities as in sections 1 and 2 of the present chapter:

m is the length of a rectangular plate, or the side of a square plate, in inches;
n is the breadth of a rectangular plate in inches;
m being greater than n in the case of rectangular plates:

Flat circular plates: $\quad p = \frac{t^2\,k}{r^2}; \quad$ [X.] $\qquad t = r\sqrt{\frac{p}{k}}; \quad$ [X.a]

Flat rectangular plates: $\quad p = \frac{4\,t^2\,(m^4 + n^4)\,k}{3\,m^4 \times n^2}; \quad$ [XI.] $\qquad t = .866\,m^2 \times n\sqrt{\frac{p}{k\,(m^4 + n^4)}}; \quad$ [XI.a]

Flat square plates: $\quad p = \frac{8\,t^2\,k}{3\,m^2}; \quad$ [XII.] $\qquad t = .612\,m\sqrt{\frac{p}{k}}; \quad$ [XIIa.]

Comparing the thickness required for a flat circular plate, as given by formula [X*a*.], with the thickness of a cylindrical shell of equal radius and of equal strength, as given by formula [III.], section 2 of the present chapter, viz., $T = \frac{p\,r}{k_1}$, we find

$$\frac{t}{T} = \frac{\sqrt{\frac{p}{k}}}{\frac{p}{k_1}}.$$

For a boiler 3 feet in diameter and having a cylindrical shell $\frac{3}{8}$ inch thick, single-riveted, the solid unstayed flat end-plate would have to be about 2 inches thick to make it as strong as the cylindrical shell. It is, however, impracticable to use such heavy plates in boiler-construction; extensive flat surfaces of boilers are therefore supported by stays or stiffened by various contrivances, so that they may be formed of relatively thin plates. Various methods of staying flat surfaces will be described, and rules for proportioning braces will be given, in chapter x.

Experiments on the strength of flat ends of cylindrical vessels, described by Robert Wilson in *Engineering*, September 28, 1877, indicate that the actual breaking strength of flat plates is much greater than that given by the above formulæ, and that the flat end-plates of boilers receive a great access of strength and stiffness by flanging their edges. But flat plates begin to bulge out with very low pressures, and the springing of the plates as the pressure is alternately applied and relieved destroys them inevitably in the course of time by grooving or channelling.

The stiffness of plates is greatly increased by buckling; and when the surfaces are not too large buckled plates are sometimes used in boilers instead of stayed flat plates. Rankine gives the following rule for calculating "the load, uniformly distributed over a buckled plate, which will crush it, the plate being square and fastened all around the edges: *Multiply the depth to which the plate is buckled by the square of the thickness, both in inches, and by* 165; *the product will be the crushing load in tons, nearly.* Central load which crushes a buckled plate about one-third of uniformly-distributed load."

6. Strains on Braces and their Attachments.—When a boiler is composed of thin, flat plates offering little resistance to bending, it may be assumed without serious error that the stress experienced by a brace is the resultant of the whole pressure acting perpendicularly to the portion of the plate supported by the brace. When the plates are increased in thickness, or are strengthened by angle or T-irons, their increased resistance to bending causes a corresponding diminution of the stress on the braces.

A brace standing perpendicular to a thin, flat plate experiences a tensile stress equal

to the total pressure borne by the supported surface. This may be expressed by the equation:

$$T = p\,S \quad \text{[XIII.]},$$

when $S =$ the area of the supported surface in square inches;
$p =$ the steam-pressure in pounds per square inch;
and $T =$ the total tension, in pounds, of the brace.

The tension of an *oblique* brace is equal to the tension which a perpendicular brace supporting the same surface would experience, divided by the cosine of the angle which the oblique brace forms with a perpendicular to the supported surface (see figure 7), or

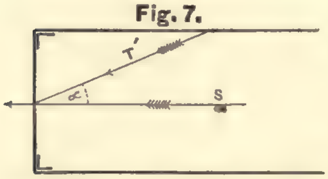
$$T^1 = \frac{p\,S}{cos.\ \alpha}. \quad \text{[XIV.]}$$

When T^1 is resolved into a pair of rectangular components acting respectively in a perpendicular and parallel direction to the supported surface, the latter component is equal to

$$T^1\ sin.\ \alpha = p\,S\ tang.\ \alpha, \quad \text{[XIV.}a\text{]}$$

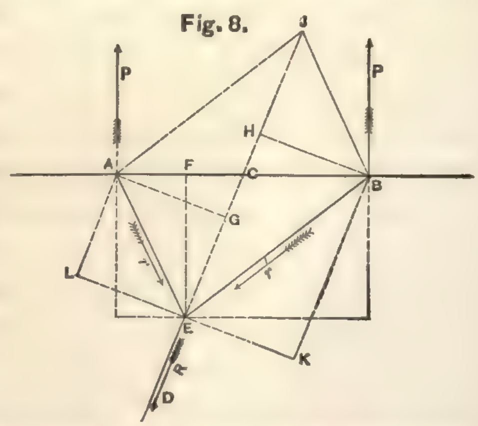
and produces a bending strain on the brace when its ends are rigidly fastened so that its angular position is fixed. When the ends of the oblique brace are attached by movable joints—for instance, by an eye and pin—offering little or no resistance to a change in the angular position of the brace, the component $T^1\ sin.\ \alpha$ exerts a thrust on the plate to which the brace is attached, tending to produce buckling.

Fig. 7.



In order to investigate the various strains obtaining in a system of oblique bracing, and the conditions required for the establishment of equilibrium, the braces shown on Plate (VII.), which tie the top of the boiler to the sides of the tube-boxes, are taken as an example. The top of the boiler is stiffened by T-irons, to which the branch-braces are attached; the latter being spaced so that each one supports an equal area of plate. The points of attachment, A, B, and D, are given, and the main brace, E D, is to have such a direction that the resultant of the stresses on E A and B E does not produce flexure, but simply tension on E D.

Fig. 8.



Let P P represent the resultants of the forces acting at right angles to the supported plate at the point of attachment of the oblique branches, A E and B E, to the T-iron;

R = the corresponding stress on the brace D E; and

r, r' the stresses on A E and B E respectively. (See figure 8.)

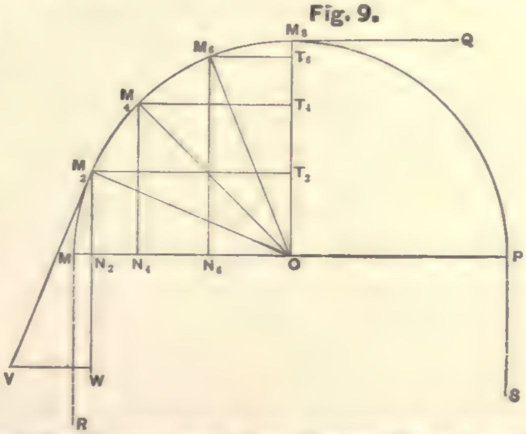
In order to balance the equal forces P P, the components of r and r', normal to A B, must each be equal in amount and opposite in direction to P P; this condition is fulfilled when $r = \frac{P}{cos.\ AEF}$, and $r' = \frac{P}{cos.\ BEF}$. The components of r and r', parallel to A B and equal to P $\times$ *tan.* A E F and P $\times$ *tan.* B E F respectively, are resisted by the stiffness of the T-iron.

The forces r and r' being each resolved into two rectangular components, respectively parallel and normal to E D, the sum of the former gives the tension of the brace E D, while the normal components L E and K E tend to deflect E D. Equilibrium requires that these normal components of the forces r and r' should be equal in amount and opposite in direction, so that they balance each other; and that the component of the tension R, normal to A B, should be equal to 2 P, or $R = \frac{2P}{cos.\ FEC}$. These conditions are fulfilled when the prolongation of E D intersects the line A B at its centre, or when A C = B C. The following proportion then exists between the force P and the tension of the main brace and of the branches—P : R : r : r' : : E F : 2 E C : A E : B E.

When the direction of E D is normal to A B the foregoing conditions give the equations R = 2 P, and $r = r'$.

7. Strains on Circular Arcs.—An internal normal pressure on any point of an arc produces at such a point a tension acting in a tangential direction, equal to the normal pressure multiplied by the radius of curvature at the point in question; consequently, when the flat sides of the shell of a boiler are connected by a circular arch—forming tangential planes to the cylindrical surface—they experience, per unit of length, a tension equal to the product of the pressure per unit of area and the radius of the arch.

Fig. 9.



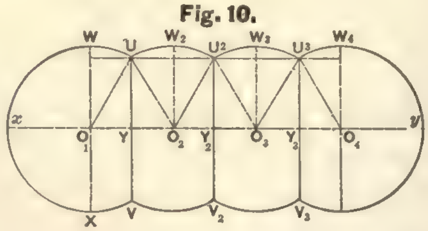
When the shell is formed by combining several cylindrical arches, as in "Emery's Connected-Arc Boiler" (see figure 92), the strains on the braces which keep the system in equilibrium under pressure may be found in the following manner:

If the semicircle M P represents the cross-section of a cylindrical arch subjected to internal fluid pressure (see figure 9) we may

represent the resultant tangential force at any point of the circumference—M_2, for instance—by a tangent line M_2 V made equal to the radius M_2 O. Resolving this tangential force M_2 V into two rectangular components, represented in magnitude and direction by the lines V W and M_2 W, respectively parallel and perpendicular to the diameter M P, we find that, since the triangle M_2 V W is similar and equal to the triangle O M_2 N_2, line M_2 N_2 (equal to the sine of arc M M_2) and line O N_2 (equal to the cosine of arc M M_2) represent the intensity of the rectangular forces which balance the tangential force at the point M_2, each of said rectangular components acting, however, in the direction of the other.

"If we consider M P and M_3 O rectangular co-ordinate axes, passing through the centre O of the circle, then the two forces required to hold in equilibrium the end of any arc forming part of the quadrant M M_3 will be measured respectively by the projections of the arc and of its complement upon the co-ordinate axes, and equal the length of such projections multiplied by the pressure per superficial unit. For instance, the horizontal component required to balance the tangential force at M_2 is measured by M_2 N_2 = sin. M_2 O M = O T_2, or the projection of the arc M_2 M on axis M_3 O, and the strain equals O T_2 multiplied by the pressure per superficial unit. The vertical component is similarly measured by N_2 O = cos. M_2 O M, or the projection of the arc M_2 M_3, which is the complement of arc M M_2, on the axis M P; and the strain equals N_2 O multiplied by the pressure per superficial unit."

Fig. 10.



If figure 10 represents a section of a boiler consisting of a series of connected circular arcs of equal radii—the centres, O_1, O_2, O_3, and O_4, of the circles all being located in the horizontal line $x\ y$—then, according to the foregoing demonstration, the horizontal component of the tangential force at U due to the pressure on arc x U may be represented by U Y, and the horizontal component of the tangential force at the same point U, due to the pressure on arc U U_2, may likewise be represented by U Y, but it acts in the opposite direction; consequently these two horizontal components of the tangential forces of the adjoining arcs balance each other. The vertical components of the tangential forces acting at the same point may be represented by the horizontal projections of the arcs W U and U W_2—viz., O_1 Y and Y O_2—both acting in the same direction. The same reasoning applies to the points U_2, U_3, V, V_2, V_3. Supposing the above figure to be symmetrical with regard to the axis $x\ y$, the system of connected arcs will be held in equilibrium by the vertical ties U V, U_2 V_2, U_3 V_3, each one of which has to

sustain a pull, for each unit of length supported, equal to the pressure per unit of area multiplied by the distance between the centres O_1 O_2, O_2 O_3, and O_3 O_4 respectively.

Fig. 11.

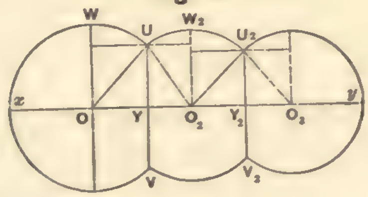
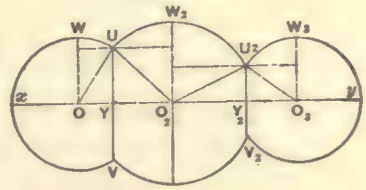


Fig. 12.



The same rule applies to the cases illustrated in figures 11, 12, where the connected arcs have different radii, but have their centres on the same horizontal line x y.

When the centres of the connected arcs do not lie on the same horizontal line x y, as in figures 13, 14, the strains on the vertical ties are measured as before by the horizontal distance between the centres—viz., $O\,Y + Y_5\,O_2$. But in figure 13 the horizontal strain of the arc W U is measured by U Y, while that of the arc $U\,U_2$ is measured by

Fig. 13.

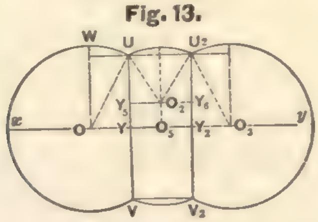
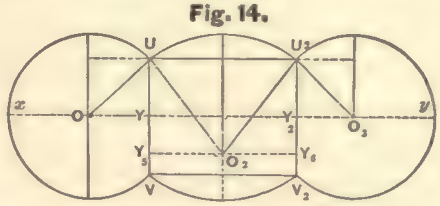


Fig. 14.



$U\,Y_5$, less than U Y; hence the arc W U tends to straighten the arc $U\,U_2$ by a force measured by $U\,Y - U\,Y_5 = Y\,Y_5$; this action has to be prevented by a tie-rod, $U\,U_2$.

In figure 14 the horizontal strains of the middle arc $U\,U_2$ being greater than those of the outer arcs by an amount $Y\,Y_6$, the outer arcs will fail of themselves to furnish sufficient support, and a strut must be placed from U to U_2, which has to sustain a compressive strain measured by $Y\,Y_6$. (See paper on 'Connected-Arc Marine Boilers,' by C. E. Emery, read before American Society of Civil Engineers, December, 1876.)

CHAPTER VII.

DESIGN, DRAWINGS, AND SPECIFICATIONS.

1. General Considerations governing the Design of Marine Boilers.—The designing of a marine boiler, especially for a war-vessel, involves the fulfilment of many conditions which are to some extent antagonistic; hence compromises have to be made, and some advantages with regard to economic and potential efficiency have to be sacrificed to other essential conditions. The principal conditions to be satisfied in the design of a boiler may be considered under the following heads: (1) The boiler must be able to furnish the power required; (2) its parts must be proportioned and arranged with regard to economic efficiency, durability, and economy in construction; (3) every part of the boiler must possess the necessary strength.

The principal restriction imposed on the designer of marine boilers of a given power is the limitation with regard to the weight of, and the space allotted to, the boilers proper and their attachments, the fire-room and the fuel. In a man-of-war, where it is especially important that all parts of the machinery should be placed as low as possible in the vessel, it is generally stipulated that no part connected with the steam-space of the boilers shall reach above the water-line. In marine boilers of the ordinary type, having the tubes or flues arranged over the furnaces, the area of the grate-surface is the principal element which determines the space occupied by the boilers in the length and breadth of the vessel. It is, therefore, convenient to determine the grate-surface in the first place, and to proportion and arrange the other parts of the boiler afterward according to the conditions imposed.

The width of the fire-room must exceed the length of the grate by at least two feet, in order that the tools used in the management of the fires may be manipulated without hindrance. In general the most economical disposition of the room is made by arranging the boilers in pairs, facing each other, with the fire-room between them.

2. Boiler-power.—The power of a boiler is measured by the weight of steam which it can generate in a unit of time. It is customary to measure the *relative* evaporative efficiency of boilers by the number of pounds of water of 212° that can be evaporated under atmospheric pressure in a unit of time; but the *actual* power of a boiler must be calculated from the weight of steam of the working pressure that can be generated

in a unit of time from the feed-water as delivered into the boiler. The average temperature of the feed-water of marine boilers may be taken as 115° when no heaters are used.

The number of heat-units that can be made available and the weight of water of a given temperature that can be evaporated under a given pressure in a unit of time in a given type of boiler, under different conditions with regard to fuel, draught, rate of combustion, and proportion of heating-surfaces, are to be calculated according to the laws governing combustion and evaporation, and from the experimental data given in chapters ii. and iii. of this treatise.

Marine engines consume from 20 to 30 lbs. of steam per indicated horse-power per hour, the latter quantity being consumed by engines using saturated steam of about 35 lbs. pressure above the atmosphere, with a moderate rate of expansion, the cylinders having no steam-jacket; the former quantity is required for the best types of engine using dry steam of from 60 to 80 lbs. pressure above the atmosphere, working with a high rate of expansion, the cylinders being provided with a steam-jacket. A marine boiler of ordinary type and proportions, using natural chimney-draught, produces under these conditions with anthracite coal from 3.5 to 5.5 indicated horse-powers per square foot of grate, with a free-burning, semi-bituminous coal from 4.5 to 7.5 indicated horse-powers per square foot of grate. With forced draught as many as 10 indicated horse-powers per square foot of grate have been developed by several large English naval vessels of recent construction, during their full-power trial for six consecutive hours at sea, by using from 25 to 30 lbs. of a carefully-selected free-burning coal per square foot of grate per hour.

In a large number of locomotive boilers, containing from 52 to 90 square feet of heating-surface to each square foot of grate-surface, the rate of combustion increasing from 43 to 126 lbs. of coke with the above proportions of heating-surface, the average evaporation was, according to D. K. Clark, 9 lbs. of water, at the ordinary temperatures and pressures, per pound of coke.

3. Various Types of Marine Boilers.—Various types of marine boilers are distinguished either by the form of their shell or by the arrangement and position of their flues or tubes. The class of "*sectional*" or "*tubulous boilers*" will be considered separately in section 10, chapter xi.

Boiler-shells are made rectangular or cylindrical, or present various combinations of rectangular and cylindrical figures.

The rectangular shell possesses the great advantage that it is easily adapted to any arrangement of the internal parts and to the space assigned to the boiler in the vessel.

The furnaces, connections, tubes, and the steam and water spaces may be arranged in the most advantageous manner, as well with respect to evaporative efficiency as with respect to accessibility and economy in weight and space.

The cylindrical shell has the advantages of strength and of simplicity of construction; but the circular form restricts within narrow limits the choice of the form, arrangement, and proportions of the internal parts; the steam-space is small relatively to the height of the boiler, and the water-level is contracted; much space in the vessel is wasted in the spandrels formed by the shells of adjacent boilers. All these objectionable features become more exaggerated as the diameter of the boiler decreases; besides, with a diminished diameter the number of the boilers has to be increased, and consequently the number of separate attachments, thus increasing the cost, the weight, and the liability of the boilers to derangement.

The form given to the shell of boilers presents often a combination of rectangular and cylindrical figures; in this manner a compromise is effected between the respective advantages and disadvantages of rectangular and cylindrical boilers.

Shells having an approximately oval cross-section have been extensively used of late in English naval vessels, with steam-pressures of 60 or 70 lbs. above the atmosphere. The furnaces in these boilers are cylindrical, and when the larger diameter of the oval shell is placed horizontally furnaces of larger diameter can be used than with circular boilers of equal height. When the larger diameter of the oval shell is placed vertically a larger and higher steam-space is obtained for the same amount of grate-surface. With the oval shell the principal advantage of the circular shell is sacrificed—viz., the absence of bracing and the uniform distribution of the strain.

Boiler-shells have been formed of a number of circular arcs joined to one another and tied together at their junction by braces, forming chords of these arcs. This system, as developed by Charles E. Emery, is illustrated in figure 92, and the proper mode of bracing such structures is discussed in section 7, chapter vi. This system enables us to extend the boiler in the direction of its length and height indefinitely as in the rectangular boiler, and independently of the radius of the circular arcs; but the advantages of the simple circular shell—viz., absence of bracing, simplicity of construction, and accessibility—are completely sacrificed. (See section 1, chapter ix.)

The characteristic features of flue and tubular boilers will be discussed in sections 1 and 2, chapter xi., where illustrations of several kinds of marine flue-boilers will be given.

Tubular boilers have superseded entirely flue-boilers for marine purposes; but flues are sometimes used in them in combination with tubes.

Tubular boilers may be divided into two grand groups—viz., 1st, the *water-tube* type, embracing all those boilers in which the larger portion of the heating-surface is arranged in tubes containing the water and having their exterior surfaces acted upon by the gaseous products of combustion; 2d, the *fire-tube* type, embracing all those boilers in which the larger portion of the heating-surface is arranged in tubes having their exterior surfaces surrounded by the water and their interior surfaces acted upon by the gaseous products of combustion, which pass through them on their way from the furnace to the chimney. Each one of these groups may be subdivided according to the position of the tubes, whether vertical, inclined, or horizontal, and according to their location—viz., whether they are placed above, behind, or at the sides of the furnaces. The considerations governing the choice of location and position of the tubes in marine boilers are briefly stated in section 3, chapter xi.

"In the present state of marine steam-engineering the choice of boilers may be considered as restricted to the vertical water-tube and the horizontal fire-tube boilers, both having their tubes arranged above their furnaces." . . . "Recourse will be had to other arrangements of tubes relatively to the furnaces only when considerations quite independent of boiler-construction control; as, for example, in light-draught vessels of war, where it is a *sine qua non* that the entire boiler and its dependencies be placed below the water-level. But wherever the choice is not thus trammelled one of the above types will certainly be selected; because, in a given space, both on the vessel's floor and cubically, they allow the proper distribution and proportion of parts, and the obtaining of the maximum economic and potential evaporation with the least weight, cost, and external surface for radiation; also, with the least weight of contained water, and, when placed in pairs facing each other—the fire-room being in common—with the least space for fire-room. These types are the most convenient, too, for repair, examination, and sweeping, all of which can be done, without trouble or special provision, from the fire-room, whence access is easily had to the interior." (*Isherwood*, '*Experimental Researches*,' vol. ii.)

Plates VI., VII., and XVII. represent the two kinds of boilers which were in general use in United States naval vessels while the working pressure of steam did not exceed 45 lbs. per square inch above the atmosphere—viz., the vertical water-tube boiler of the Martin type, and the horizontal fire-tube boiler, both having a rectangular shell and the tubes placed over the furnaces. The relative evaporative efficiency of these two types of boiler, as determined by numerous experiments conducted under the direction of the Bureau of Steam-Engineering of the United States Navy Department, is as follows: When each boiler has 25 square feet of heating-surface per square foot of

grate-surface, a calorimeter equal to one-eighth of the grate-surface, and a chimney 60 feet high, the boiler being placed in the hold of the vessel and the air having to reach the ashpits through restricted hatches from the upper deck, the maximum rate of combustion with natural draught is for the horizontal fire-tube boiler 16 lbs. of anthracite per square foot of grate, and for the vertical water-tube boiler 12½ lbs. of anthracite per square foot of grate; and with these rates of combustion the former will furnish 4.36 per cent. more steam, but at the expense of 28 per cent. more fuel. With the above proportions the space occupied by, and the weight of, the boiler proper and the water contained in it will each be a few per cent. less with the vertical water-tube than with the horizontal fire-tube boiler. The latter has the practical advantages that the tubes are more easily swept and that leaky tubes are easily plugged, even while the boiler is in operation, and can be taken out and replaced without disturbing the bracing of the boiler.

The boiler of the U. S. S. *Lackawanna* (Plates VI., VII.), containing seven furnaces with an aggregate grate-surface of 136.5 square feet, and having a length of 25 feet, is as large as it is convenient to build rectangular boilers, on account of the limit imposed by the size of the boiler-hatches.

Rectangular boilers have been built in some instances with two tiers of furnaces, placed directly over one another; each pair of furnaces discharging their gases into a common back-connection and through a common set of tubes. This arrangement has been adopted to augment the area of grate-surface contained within a single shell without increasing the length and breadth of the boiler, when an increase of height was admissible. This arrangement has, however, not given satisfactory results; the upper tier of furnaces obstructs the free escape of steam generated on the lower furnace-crowns; since a platform has to be built to fire the upper furnaces, fan-blowers are required to furnish a sufficient air-supply to the lower furnaces and to ventilate the lower fire-room.

With cylindrical shells vertical water-tubes cannot be used without increasing greatly the amount of stayed surfaces. They may, however, be used advantageously in oval shells in which the larger diameter forms the vertical axis, as the flat portions of the shell may be tied directly to the flat vertical sides of the tube-boxes.

Fire-tubes, placed in the direction of the axis of the cylinder, can be arranged in the most convenient manner, and are used almost exclusively, in cylindrical marine boilers.

In cylindrical boilers the diameter of the shell limits the number and the diameter of the furnaces. In the type of boilers represented on Plates VIII., XI., and XII., having a cylindrical shell and cylindrical furnaces, and horizontal fire-tubes arranged

above the furnaces, when the shell is from seven to eleven feet in diameter the number of furnaces is generally two, and when the shell is from eleven to fourteen feet in diameter the number of furnaces is generally three. When the working pressure of steam is as high as 80 lbs. above the atmospheric pressure the diameter of boilers seldom exceeds fourteen feet, on account of the difficulty of working the heavy plates required in the construction of the shell. When the shell is less than seven feet in diameter two cylindrical furnaces may be used with the tubes arranged behind the furnaces; but with return-tubes a single cylindrical furnace has to be used, and the tubes have to be arranged partly at the sides of the furnace. With the latter arrangement it is found that the draught is relatively sluggish (see "Boiler Experiments," *Franklin Institute Journal*, March, 1879), and the furnace-crowns are inaccessible for cleaning unless the tubes are removed; in case the furnace is of large dimensions and the tubes are closely spaced the circulation of the water is imperfect and the steam escapes with difficulty from the furnace-crowns. This arrangement should be avoided in marine boilers where salt water has to be used; but it is often used to advantage in boilers of steam-launches and similar small craft, supplied with fresh water from tanks and using a steam-blast, because with this arrangement the bulk of the boiler and the weight of water contained in it may be reduced considerably. (See Plate XVI.)

The boiler represented on Plate XV., having furnaces at both ends, illustrates a method of increasing the grate-surface within a shell of a given diameter without affecting the proportions of heating-surface, calorimeter, and steam-room to grate-surface. Compared with two single-end boilers of equal diameter, grate-surface, and proportion of internal parts, the bulk, weight, and cost of construction of the double-end boiler is less, owing to the omission of the two back-heads and the attachment of braces to them; with the number of boilers the number of valves, pipes, and other apparatus required for each separate boiler is likewise diminished; the total space in the vessel occupied by double-end boilers is somewhat greater, because each end requires a separate fire-room.

In order to reduce still more the length and the weight of double-end boilers the water-space separating the back-connections of each pair of opposite furnaces is sometimes omitted, so that the two furnaces discharge their gases into a common back-connection. But with this arrangement the action of the two currents of gas entering the back-connection from opposite sides is prejudicial to an active and reliable draught.

The boiler of the U. S. S. *Daylight* (figure 1, Plate III.) illustrates a type of boiler frequently used on American steam-vessels. The front portion of the shell is made rectangular in plan, with flat sides and a semi-cylindrical top; the back portion is cylin-

drical, with its top a horizontal continuation of the top of the semi-cylindrical front portion. The cylindrical portions, which are of an oval cross-section in the present example, are more frequently of a circular cross-section. The rectangular front admits of the most advantageous proportions of the furnaces, and the use of the cylindrical form for the rest of the shell simplifies the construction. A high steam-drum surrounding the uptake affords additional steam-room and superheating surface. Flues of large diameter extend from the combustion-chambers at the back of the furnaces to the back-connections, and the horizontal return-tubes are likewise relatively of a large diameter and of great length. This arrangement is favorable to a high rate of combustion; the draught is frequently forced by fan-blowers in this type of boiler.

Figures 2 and 3, Plate III., illustrate arrangements of the tubes adopted in marine boilers where the height of the boilers has to be reduced at the expense of the room occupied on the floor of the vessel. The lower flue in the boilers of the U. S. S. *Mahaska* is sometimes omitted, the vertical water-tubes being arranged directly behind the furnaces; in other boilers the vertical water-tubes have been arranged at the sides of the furnaces, the upper tube-sheet being on a level with the furnace-crown. A similar arrangement is sometimes adopted with horizontal fire-tubes. All these arrangements present the advantages that the water-surface from which the steam escapes is about twice as great as when the tubes are placed above the furnaces, and that the steam generated on the furnace-crowns escapes freely, not having to pass through the narrow water-spaces in or between the tubes. These advantages are of great importance when a high rate of combustion is employed.

The type of boiler having horizontal fire-tubes placed directly behind the furnaces is called the "*locomotive type*," because this arrangement is always adopted in the boilers of locomotives. Figure 2, Plate III., illustrates this arrangement adapted to a marine boiler with a rectangular shell, while Plates IV. and V. illustrate the same type of boiler built for railroad purposes. In the latter the front portion of the shell is always rectangular in plan, with flat sides, in order to get a roomy furnace, and the top is generally made semi-cylindrical; the back portion of the shell is cylindrical. The tubes are of small diameter and great length, and are closely spaced in order to get a large heating-surface within a small space. All the water-spaces are narrow; the whole boiler is made long but low; its bulk and weight are reduced as much as possible. It is designed to generate steam rapidly, and to have a high economic and potential evaporation; it is always worked with a steam-blast.

The same type of boiler is frequently used for marine purposes, in steam-launches and similar small craft, when fresh water is used to feed the boiler. In case salt water

has to be used at times it is better to make the whole shell cylindrical, in order to reduce the stays and braces required to a minimum.

The vertical fire-tube boiler having a cylindrical shell (see figure 1, Plate XXVIII.) is capable of a high rate of combustion, but its economic evaporative efficiency is small, unless the tubes are made very long and the proportion of heating to grate surface is unusually large. The water-level is carried some distance below the upper tube-sheet, and the upper ends of the tubes and the uptake furnish superheating-surface. The bulk and weight of this boiler are relatively small. This type is frequently used for boilers of steam-launches and road-engines. It has also been used for large marine boilers, but is not well suited for them, because the arrangement of the tubes makes the interior of the boilers almost inaccessible, and the great length of the tubes makes it difficult to clean them or remove and replace them.

Dickerson's marine boiler had a rectangular shell; inclined water-tubes were placed directly over the furnace, and the products of combustion rising from the grate enveloped these tubes and then passed through vertical fire-tubes, placed above them in the steam-space, into the uptake. The front and back of the boiler had large openings, closed by cast-iron covers secured by bolts, to make the water-tubes accessible. This boiler may be regarded as a connecting-link between the preceding types of tubular marine boilers and the *sectional water-tube boilers* described in section 10, chapter xi. With the rate of combustion usual in marine boilers the steam generated in the inclined water-tubes escaped with difficulty, and the gaseous products of combustion entered the uptake at a high temperature; in consequence the tubes were soon burnt, and the boilers have gone out of use after a short trial.

TABLE XXII.,

SHOWING THE DIMENSIONS, PROPORTIONS, AND WEIGHTS OF BOILERS OF VARIOUS TYPES.

Name of vessel.	Number of plate.	1 Description of boiler.	2 Number of boilers.	3 Total number of furnaces.	4 Total area of grate-surface in square feet.	5 Square feet of water-heating surface per square foot of grate-surface.	6 Square feet of steam-superheating surface per square foot of grate-surface.	7 Square ft. of grate-surface per sq. ft. of cross-area through tubes or flues for draught.	8 Square feet of grate-surface per square foot of cross-area of smoke-pipe.
U. S. S. *Lackawanna*	VI. and VII.	Rectangular shell; vertical water-tubes; Martin type	3	14	273.0	32.051	0.733	5.662	5.611
" *Mahaska*	III.	Rectangular shell; vertical water-tubes; Bartol's patent	2	6	96.25	29.275	0.977	7.018	12.071
" *Plymouth*	XVII.	Rectangular shell; horizontal return fire-tubes; superheater in uptake	4	20	390.00	18.420	5.870	11.175	6.932*
" *Daylight*	III.	Elliptical shell; flues and horizontal return-tubes	1	3	84.50	30.355	1.302	9.565	10.187
" *Kansas*	III.	Rectangular shell; locomotive type	2	6	108.00	28.500	0.741	5.455	12.401
" *Shockokon*	XXI.	Cylindrical shell; return ascending flues.	1	3	64.58	21.058	3.020	8.772	4.737
" *Morse*	XXI.	Cylindrical shell; double-return drop-flues	1	2	55.805	21.901	1.792	9.357	7 085
" *Nipsic*	XII.	Cylindrical shell; horizontal return fire-tubes	6	12	192.00	25.600	0.820	7.080	7.380
" *Miantonomoh* and class	VIII.	Cylindrical shell; horizontal return fire-tubes	6	18	378.00	23.290	1.339	6.070	....
Steamer *Lookout*	XI.	Cylindrical shell; horizontal return fire-tubes	1	2	23.00	22.520	2.000	7.600	....
" *Lord of the Isles.*	XV.	Cylindrical shell; three furnaces at each end	2	12	171.00	29.023	3.600	3.805	4.444
" *Estelle*	XXVII.	Herreshoff coil-boiler	1	1	38.48	13.980		1.511	7.841

* Two telescopic smoke-pipes. † Water-level 9 inches above tubes.

TABLE XXII.—(*Continued.*)

SHOWING THE DIMENSIONS, PROPORTIONS, AND WEIGHTS OF BOILERS OF VARIOUS TYPES.

[illegible]	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Height of smoke-pipe above level of grate, in feet.	Capacity of steam-room in boiler-shell, in cubic feet.	Capacity of steam-room in steam-drums, in cubic feet.	Capacity of steam-room in superheating chambers or pipes.	Total capacity of steam-room in cubic feet.	Weight of boilers, including doors, uptakes, plates, etc., but excluding smoke-pipe and grate-bars.	Weight of smoke-pipe in pounds.	Weight of grate-bars in pounds.	Total weight of boilers in pounds.	Weight of water in boilers in pounds.	Height of boilers to top of shell, in feet.	Height of boilers to top of steam-drum, in feet.	Length occupied by boilers and fire-room in the vessel.	Width occupied by boilers and fire-room in the vessel.	Working pressure of steam in pounds per square inch above the atmosphere.
49.50	1200	200	....	1400	224,700	.....	15,000	......	.....	10.25	13.00	25.00	29.00	35
59.50	[illegible]	....	....	866	93,000	5,300	8,590	106,890	68,500	8.00	....	29.00	20.166	40
56.00	1100†	....	224	1324	265,000	21,362*	20,000	306,362	115,000†	9.00	....	38.50	27.500	40
43.50	670	130	....	800	......	.....	......	......	56,930	10.66	18.00	25.25	15.000	25
50.00	930	....	....	930	......	......	......	......	......	7.25	....	26.75	21.333	30
55.75	653	220	....	873	......	......	......	......	......	10.75	22.00	32.00	12.000	40
45.75	760	32	....	792	......	......	......	......	36,700	9.75	14.75	33.00	9.750	15
53.50	740‡	140	[illegible]	900	185,000	14,350	10,000	209,350	78,360‡	9.00	9.00	31.50	28.25	80
....	1589	300	135	2024	374,000	7,800	24,000	405,800	191,000‡	12.13	12.75	38.00	34.00	80
....	35	60	....	95	19,780	......	1,200	......	8,740	7.00	12.50	15.6	8.00	80
....	680	720	....	1400	.....	......	......	......	......	13.00	27.75	29.00	28.500	75
28.00	17.24§	9.4	....	26.64	......	......	......	16,500	1,100	11.25	....	18.00	8.250	[illegible]

‡ Water-level 6 inches above tubes. § Half capacity of coil.

TABLE XXIII.

SHOWING THE ECONOMIC EVAPORATION OF BOILERS OF VARIOUS TYPES, WITH DIFFERENT RATES OF COMBUSTION, AND WITH DIFFERENT PROPORTIONS OF CALORIMETER, HEATING-SURFACE, AND GRATE-SURFACE.

Name of vessel.	1 Number of plate where the boiler is illustrated.	2 Type of boiler.	3 Square feet of heating-surface to one square foot of grate-surface.	4 Square feet of grate-surface to 1 sq. ft. of opening between or through tubes for draught.	5 Pounds of anthracite combustible consumed per hour per sq. ft. of grate.	6 Pounds of anthracite combustible consumed per hour per sq. ft. of heating-surface.	7 Pounds of water evaporated under atmospheric pressure from 212° F. by 1 lb. of anthracite combustible.	8 Per centum of total heat of combustion utilized in evaporation.	9 Temperature of products of combustion in uptake.	10 Date of experiment.
* U. S. S. *Mahaska*.	III.	Verti'l water-tubes (Bartol's patent).	29.275	7.018	5.505	0.228	13.873	93.04	298.2	1863
* " *Daylight*...	III.	Horizontal return fire-tubes.	30.355	7.870	6.511	0.214	11.199	75.10	280.1	1863
* " " ...	"	"	30.355	7.870	8.270	0.272	11.879	79.66	261.0	1864
* " *Kansas* ...	III.	Locomotive type..	28.500	5.455	14.103	0.596	10.196	68.38	495.7	1863
* " " ...	"	"	28.500	6.601	13.124	0.552	10.790	72.36	466.9	1863
* " " ...	"	"	28.500	8.148	13.176	0.565	10.789	72.35	535.6	1863
* " " ...	"	"	28.500	10.313	10.754	0.464	11.570	77.59	497.5	1863
* " *Shockokon*	XXI.	Return-flues......	21.058	8.772	15.209	0.723	8.673	58.16	....	1864
* " " .	"	"	21.058	8.772	8.843	0.420	8.660	58.08	....	1864
* " *Morse*.....	XXI.	Double-return drop-flues.	21.901	9.357	9.372	0.428	10.257	68.78	....	1863
† S. S. *Estelle*	XXVII.	Herreshoff coil-boiler.	13.283	1.511‡	10.698	0.805	9.938	66.64	....	1877

* Isherwood, 'Experimental Researches,' vol. ii. † 'Report of Board of United States Naval Engineers,' 1878.

‡ Proportion of grate-surface to cross-area of chimney = 7.811 to 1.

4. Space and Weight required for Boilers of a given Power (*Isherwood*, '*Experimental Researches*,' vol. ii.)

"In a steamer a certain space is to be allotted to the boiler, fire-room, and coal for a given speed to be maintained a given time; and the problem is so to apportion them that this space shall be a minimum. To fulfil the speed condition a certain weight of steam per hour must be furnished. Now, if a boiler with a high rate of combustion be employed a less space will be required for it and its fire-room, but more space will be required for the coal, as the economic evaporation will be less; and, *vice versa*, if a boiler with a low rate of combustion be employed a greater space will be required for it and its fire-room, but less space will be required for the coal, on account of its greater economic evaporation. It is evident there is a point where the aggregate space is a minimum. If the cost of fuel be considered an item of importance, it extends the problem, in a commercial vessel, to whether it is not advantageous to employ a boiler of still lower rate of combustion and higher economic efficiency, and take the additional space required for it from the portion allowed to cargo. In a war-steamer this additional space would be at the expense of its military power.

"In the following table will be found the solution of the above problem for the horizontal fire-tube boiler having the tubes above the furnaces. The determination is made for the case in which the vessel is to carry a supply of fuel sufficient for 200 hours' maximum steaming. . . . Further, the determination is made both for aggregate space occupied and weight carried, for the fuel, and the boilers and fire-room.

"In making these calculations the boiler is assumed to be 10 feet 3 inches long at the level of the grates, 9 feet 9 inches high, and of sufficient width or frontage to give the requisite grate-surface with furnaces 3 feet wide, containing grates 6 feet 6 inches long. The fire-room is assumed to extend in the fore and aft direction of the vessel, and to be 8 feet 6 inches wide, the boilers being arranged on each side of it in opposite pairs.

"The ratio of the heating to the grate surface is taken at 25 to 1, and the calorimeter at one-eighth of the grate-surface.

"The thickness of the plate for the bottom of the boiler, and for the furnaces and the ashpits, is taken at $\frac{3}{8}$ of an inch, for the tube-plates at $\frac{1}{2}$ inch, and for all other parts at $\frac{5}{16}$ of an inch; all seams are taken to be double-riveted, and the boiler to be braced for a working pressure of 40 pounds per square inch above the atmosphere. . . .

"The weights taken for the boiler are the actual weights as determined by weighing exactly such boilers after completion. These weights include not only the boiler pro-

per, but everything appertaining to it, as grate-bars, smoke-pipe, doors, plates, valves, pipes, felt and sheet-lead covering, floor-plates of fire-room, and water in boilers. . . .

"The fuel is to be anthracite, with one-sixth of refuse, and the space occupied by every 53½ pounds of it to be 1 cubic foot, which is the average of bunker-stowage with this coal. . . . The maximum weight of steam to be furnished per hour is taken at 60,000 pounds. . . .

"We find, on examining the column of space occupied by the aggregate boiler, fire-room, and anthracite, . . . that, leaving wholly out of view the economic evaporation by the anthracite, the best rate of combustion for obtaining in a given space the greatest quantity of steam per hour during 200 hours is 13 pounds of anthracite per square foot of grate-surface per hour. . . . If some importance be given to the economy of the fuel we perceive that, by reducing the rate of combustion to 10 pounds of anthracite, we can effect a saving in the fuel consumed of $\left(\frac{8.989 - 8.236}{8.236} \times 100\right) = 9.14$ per centum by increasing the space occupied $\left(\frac{59001 - 55826}{55826} \times 100\right) = 5.69$ per centum; . . . the minimum aggregate weights of boiler and its appurtenances, and of the anthracite, correspond to a rate of combustion of 11 pounds of anthracite per square foot of grate-surface per hour." It is evident that when the maximum supply of steam is to be furnished for a greater or less length of time, the weight and space occupied by the boiler and fire-room remains the same for the respective rates of combustion, while that of the anthracite increases or decreases, as the case may be.

TABLE XXIV.

EXHIBITING THE SPACE AND WEIGHT REQUIRED WITH THE HORIZONTAL FIRE-TUBE BOILER HAVING A RECTANGULAR SHELL AND THE TUBES ARRANGED ABOVE THE FURNACES, AND WITH ANTHRACITE WITH ONE-SIXTH REFUSE, TO FURNISH A GIVEN SUPPLY OF STEAM PER HOUR FOR 200 HOURS WITH DIFFERENT RATES OF COMBUSTION.

Pounds of anthracite consumed per hour per square foot of grate-surface.	Pounds of water evaporated under an absolute pressure of 54 lbs. per square inch from 120° Fahr. per pound of anthracite.	Number of square feet of grate-surface in boiler.	Space.			Weight.		
			Cubic feet of space occupied by boiler and fire-room to furnish 60,000 pounds of steam per hour.	Cubic feet of space occupied by the anthracite to furnish 60,000 pounds of steam per hour during 200 hours.	Cubic feet of space occupied by the aggregate boiler and fire-room, and anthracite, to furnish 60,000 pounds of steam during 200 hours.	Weight of boiler, including all its appurtenances, as grate-bars, smoke-pipe, doors, plates, valves, pipes, felt and sheet-lead covering, water in boilers, etc., in pounds.	Weight of anthracite, on the supposition that each cubic foot of space stows 53⅓ lbs., in pounds.	Aggregate weight of boiler and appurtenances, and of anthracite, in pounds.
6	9.383	1,065.72	54,240	23,979	78,219	1,231,866	1,278,880	2,510,746
7	9.338	917.91	46,717	24,095	70,812	1,061,012	1,285,067	2,346,079
8	9.258	810.11	41,230	24,303	65,533	936,406	1,296,160	2,232,566
9	9.150	728.60	37,082	24,590	61,672	842,189	1,311,467	2,153,656
10	8.989	667.48	33,971	25,030	59,001	771,540	1,334,933	2,106,473
11	8.775	620.32	31,627	25,641	57,268	717,028	1,367,520	2,084,548
12	8.524	586.58	29,907	26,396	56,303	678,028	1,407,787	2,085,815
13	8.238	560.25	28,514	27,312	55,826	647,593	1,456,640	2,104,233
14	7.934	540.17	27,492	28,359	55,851	624,382	1,512,480	2,136,862
15	7.621	524.87	26,713	29,524	56,237	606,697	1,574,613	2,181,310
16	7.343	510.69	25,991	30,641	56,632	590,306	1,634,187	2,224,493
17	7.111	496.33	25,261	31,641	56,902	573,708	1,687,520	2,261,228
18	6.887	484.00	24,633	32,670	57,303	559,456	1,742,400	2,301,856
19	6.690	472.03	24,024	33,632	57,656	545,619	1,793,707	2,339,326
20	6.547	458.23	23,322	34,367	57,689	529,668	1,832,907	2,362,575
21	6.404	446.15	22,707	35,134	57,841	515,705	1,873,813	2,389,518
22	6.297	433.17	22,046	35,731	57,777	500,701	1,905,653	2,406,354
23	6.190	421.44	21,449	36,349	57,798	487,142	1,938,613	2,425,755
24	6.100	409.84	20,859	36,885	57,744	473,734	1,967,200	2,440,934

5. Proportioning the Parts of a Boiler.—In the following special regard has been had to the ordinary type of marine boilers, with horizontal fire-tubes or vertical water-tubes arranged over the furnaces, and burning anthracite coal with natural chimney-draught, unless the conditions are otherwise specified.

The length and the width of the grate are limited to such dimensions as will permit the proper management of the fire, especially the cleaning of the back and of the front corners; on this account the length should never exceed 7 feet nor the width 42 inches; the grate-surface in each furnace ranges generally between 18 and 21 square feet. The grate slopes downward from the front to the back, at the rate of one inch or $1\frac{1}{4}$ inch to the foot in the length of the grate; this arrangement facilitates the firing at the back, and makes the furnace roomier at the same time.

The ashpit, even when partly obstructed by ashes, must admit a sufficient quantity of air, moving at a low velocity, to every part of the grate. This condition will generally be fulfilled when the ashpit is made roomy enough to permit the working of the fire from below the grate. With dimensions of the grate as given above, the height of the ashpit-opening in front varies from 15″ to 18″, while its width is made equal to that of the furnace.

The furnace must have sufficient height above the grate to afford room for the gases to mingle thoroughly and to permit a proper working of the fire. The height of the furnace-crown above the grate in marine boilers burning anthracite coal, with natural draught, averages from 18 to 24 inches. High rates of combustion necessitate an increase in the height of the furnace; in locomotive boilers the furnace is often made 48 inches high. Bituminous coals require a larger combustion-chamber than anthracite.

The calorimeter over the bridge-wall at the back end of the grate should be made as small as is consistent with the desired rate of combustion, in order to increase the velocity of the gases to a maximum at this point, and cause them to mingle thoroughly as they emerge into the combustion-chamber or back-connection. The area of this passage is made from $\frac{1}{7}$ to $\frac{1}{8}$ of the area of the grate in marine boilers using natural draught; when forced draught is used, and the rate of combustion is increased, the area of this passage is likewise to be increased. The opening should extend, if possible, the whole width of the grate, the area being regulated by the height.

The back smoke-connection should be as spacious as possible to afford the gases room and time to complete their combustion before entering the tubes. This condition will generally be fulfilled when sufficient room is provided to admit a man for making examinations and repairs, expanding the tube-ends, calking, etc.; the width of this chamber ranges generally between 18 and 30 inches.

The calorimeter through or between the tubes varies from $\frac{1}{6}$ to $\frac{1}{8}$ of the area of the grate-surface, the larger area being used for the higher rates of combustion; the diameter of the tubes depends to a great extent on the amount of heating-surface that is to be placed into the allotted space. The diameter of horizontal fire-tubes varies from $2\frac{1}{2}$ to $4\frac{1}{2}$ inches; smaller tubes are liable to become choked with soot and ashes, unless a very strong draught is produced by a blast. Vertical water-tubes are commonly made 2 inches in diameter, and are spaced so as to allow from $1\frac{1}{8}$ inches to $1\frac{5}{8}$ inches of clear space for the passage of the gases.

The calorimeter of the smoke-pipe varies from $\frac{1}{6}$ to $\frac{1}{8}$ of the area of the grate. When several furnaces empty their gases into a common chimney, care must be taken that the calorimeter of the uptake at different points is proportional to the volumes of gas that have to pass such points.

The total heating-surface of marine boilers using natural draught is made from 25 to 35 times the area of the grate-surface for rates of combustion ranging between 12 lbs. and 22 lbs. of coal per square foot of grate per hour. When forced draught is employed the heating-surface must be increased in proportion to the increased rate of combustion; in locomotives, burning as much as 120 lbs. of coke per square foot of grate per hour, the heating-surface is about 90 times the area of the grate-surface. The evaporative efficiency of the different heating-surfaces in a boiler varies greatly, as has been shown in chapter iii. The heating-surfaces must be arranged in such a manner as to allow the steam to escape from them as soon as formed; horizontal water-tubes are therefore to be avoided, as well as extensive flat surfaces for the bottom of flues and smoke-connections. By rounding the corners of internal square passages with a large radius the free escape of the steam and the circulation of the water will be greatly facilitated, while the strength of those parts is increased at the same time. A relatively small portion of the heating-surface in the uptake of every boiler passes through the steam-space; it is often found advantageous to increase this superheating-surface by means of various contrivances that will be described in a subsequent chapter. (See section 3, chapter xiii.)

The water-spaces surrounding the furnace and the smoke-connections should never be less than 4 inches in the clear, and, if possible, should be made $5\frac{1}{2}$ inches wide in marine boilers. Sufficient room must be left between the furnace and the tubes to admit a man to the interior of the boiler to scale the crown-sheet of the furnace and to make repairs. Manholes provided for this purpose in the front of the boiler are oval in shape, of $15'' \times 12''$ diameter; the smallest admissible size is $13'' \times 11''$.

The clear space left for this purpose above the furnace is also necessary on account

of the rapid formation of steam on the furnace-crown, as it facilitates the free circulation of the water; for the same reason it is not advisable to make the furnaces of marine boilers very wide, especially when the tubes are placed rather close to the furnace-crown.

Horizontal fire-tubes returning over the furnace should be spaced with at least 1 inch of clear space between them in a horizontal direction, and must be placed in vertical rows, in order to offer the least obstruction to the rising steam-bubbles. It is advisable to leave larger spaces, from 5 to 7 inches wide, between the tube-rows at intervals, for the passage of the descending currents of water.

The water must be carried at such a height above the back-connection and the tubes that they are not bared too readily through irregularities in the admission of the feed-water, excessive foaming, or the rolling of the vessel. With horizontal fire-tubes the water-level should be carried not less than 6 inches above the back-connection. The area of the water-level should always be as large as possible, to prevent foaming and the lifting of water.

The capacity of the steam-space depends on the number of cubic feet of steam required by the engine in a unit of time. It should be of sufficient height to prevent the lifting of the water into the steam-pipe. (See section 1, chapter xiii.)

6. Relative Value of various Forms for Boiler-construction.—Although *the spherical shell* possesses greatly superior strength over all other forms of structure, and has the additional advantage of accommodating itself to the expansive action of heat without distortion, its employment in boiler-construction is very limited on account of the comparative difficulty of giving this form to the material used. The property of the sphere of presenting less surface than any other body in proportion to its content is an objection to its use in connection with the heating-surfaces of a boiler, and its use for external shells would entail a great loss of room in waste spaces. The ends of cylindrical shells of land boilers and the top of steam-drums are often made of spherical segments; spherical strengthening-domes are sometimes attached to flat surfaces where staying by rods or gussets is inexpedient. The *Harrison boiler* is composed almost entirely of small cast-iron spheres connected by short tubes.

The cylindrical form has the most extensive application in boiler-making. It possesses next to the sphere the greatest strength; it is readily produced of any required size and of all materials used in boiler-making. Since with cylindrical forms stays and braces can be dispensed with, their use makes a boiler accessible and cheapens its construction.

The use of *flat surfaces* is in many cases unavoidable for an economic utilization of the space allowed and for the proper arrangement of the interior parts of a boiler. The

heads of the shell, the tube-sheets, and the back of the back-connection are always made flat in cylindrical marine boilers of the usual type. When the steam-pressure is not to exceed 45 lbs. per square inch above the atmosphere the outer shell of marine boilers is generally made box-shaped, with square sides and the corners more or less rounded; by using this form of boiler the space in a vessel allotted to it can be most fully utilized, and the proportions of the furnaces can also be more satisfactorily arranged than with the cylindrical boiler. On this account, in boilers designed to carry steam of high pressure, especially in locomotive boilers, the front part, containing the furnace, is often made square below and semi-cylindrical on top, while the body of the boiler, containing the flues or tubes, is made a complete cylinder; or sometimes the whole boiler is made oval in shape.

7. Factor of Safety.—All parts of a boiler must possess equal strength. The dimensions of the various parts of a boiler must not be calculated by applying a uniform factor of safety to the formulas expressing the strength of the respective shapes, but account must be taken of the continual waste taking place in all parts of a boiler in consequence of external and internal corrosion and the wasting effect of the intense heat produced in the furnace. Since the deterioration resulting from these causes affects different parts and forms in a different degree, the allowance of additional thickness of metal to be made on this account must vary accordingly. Care must also be taken that such parts as cannot be readily replaced or repaired be proportioned with an extra large margin of strength.

The plates of boilers must be proportioned and stayed not only with regard to strength, but sufficient stiffness must be given to them to prevent changes of shape under pressure. A change of shape in one direction by pressure, and returning again to its original position when the pressure is released, will sooner or later result in a crack. The same is true when braces are attached in such a way that the sheet is drawn from its true position.

The tensile stress exerted by the maximum steam-pressure on any part of a boiler should not exceed one-sixth of its ultimate strength. This factor of safety is usually employed for parts of machinery subjected to alternating stresses acting in opposite directions. The steam-pressure in a boiler cannot be considered as a quiescent load, on account of the constantly occurring, and sometimes considerable, fluctuations of pressure due to various causes; besides, the different parts of a boiler are subjected to continual expansions and contractions owing to changes of temperature, the effect of which cannot be calculated, but is very marked under certain conditions. The force exerted by expansion or contraction as the effect of change of temperature is equal to that which

would be required to elongate or compress the material to the same extent by mechanical means. The linear expansion of ordinary wrought-iron plates is .0000064 of their length for each degree Fahrenheit of increase of temperature, and the same elongation is produced by a stress of about 150 lbs. per square inch of section of metal. It must be observed that this stress produced by increase of temperature is independent of the sectional area of the plate, and if the expansion or contraction of the plate is not allowed to go on freely a corresponding stress will be exerted on the metal by a change of temperature.

In case the substitution of mild, ductile cast-steel for piled wrought-iron plates for boilers should be warranted by further practice, it may be considered safe to decrease the factor of safety to four, on account of the greater homogeneousness and uniformity of quality of the steel plates rolled from single ingots.

It must be remembered that the strength of any structure is to be measured by that of its weakest part, which in the case of boilers is the joint where the sheets are connected. The strength of various forms of joint employed in boiler-making will be discussed in the next chapter.

The 'Revised Statutes of the United States' prescribe the following rule regarding the factor of safety to be employed in determining the strength of marine boilers: "*Section* 4433. The working steam-pressure allowable on boilers constructed of plates inspected as required by this title, when single-riveted, shall not produce a strain to exceed one-sixth of the tensile strength of the iron or steel plates of which such boilers are constructed; but where the longitudinal laps of the cylindrical parts of such boilers are double-riveted, and the rivet-holes for such boilers have been fairly drilled instead of punched, an addition of twenty per centum to the working-pressure provided for single-riveting may be allowed: Provided, That all other parts of such boilers shall correspond in strength to the additional allowances so made, and no split-calking shall in any case be permitted."

In the case of large cylindrical flues subjected to compression the factor of safety should be increased to eight at least when Fairbairn's formula is employed; in addition to this the thickness of the metal must be increased $\frac{1}{16}$ or $\frac{1}{8}$ inch to allow for corrosion and other wasting influences. To allow for corrosive and other destructive influences in the case of the rectangular boiler, the lower parts of the outer shell, the water-legs, and the bottom of the back-connections are generally made from $\frac{1}{8}$ to $\frac{3}{16}$ inch thicker than the other parts of the shell; the parts exposed to an intense heat are less increased in thickness, on account of the liability of thick plates to blistering; therefore the furnaces and the sides, tops, and fronts of the back-connections receive an in-

crease of $\frac{1}{16}$ inch only; the tube-sheets, on the contrary, are still further increased in thickness, in order to allow for the loss of stiffness in consequence of the many large holes drilled in them, and to give a sufficient bearing-surface to the tubes.

Stays and braces are generally proportioned to bear a strain of from 4,000 to 5,000 lbs. per square inch of section; a more rational method of proportioning them, however, is to calculate the required cross-section, according to the pressure on the surface which they have to support, using six as a factor of safety, and adding a certain amount to the thickness or diameter thus found to allow for corrosion. Generally it will be sufficient to add $\frac{1}{4}$ inch to the thickness required for strength; but near the water-level and in narrow water-spaces the increase in thickness has to be greater. Welded parts must likewise receive an additional increase, since the metal is there more easily attacked by corrosion and the strength of welded joints varies greatly.

8. Drawings and Specifications.—After the dimensions and the general shape and arrangement of a boiler have been decided upon, the exact forms and proportions of the various parts can be most advantageously determined by making a drawing of the boiler, showing front and side elevations, and a plan, including such full or partial sectional views as are required for a complete illustration of every part of the boiler. On the drawing all dimensions necessary to guide the boiler-maker in the construction of the boiler must be plainly marked, including the thickness of the sheets, the size and position of all openings for steam, feed and blow-off pipe connections, and for man and handhole plates, safety-valves, etc., the position and attachment of the braces and stays, and the location and form of the principal seams. This drawing is generally made to a scale of 1 inch or $1\frac{1}{2}$ inches to the foot. Drawings on a larger scale are made to show in detail the devices adopted for bracing different parts of the boiler, and the various attachments of the boiler, as well as the arrangement of the uptake and chimney. In order to determine all these details intelligently it is advisable to lay down a general plan on a scale of 1 inch or $\frac{3}{4}$ inch to a foot, showing the location of the boilers in the vessel with regard to floors, keelsons, decks, beams, masts, and bulkheads, the mode of securing the boilers, their connections and attachments, the position of valves and pipes, also the ventilators, doors, stairs, ash-hoisters, and other arrangements connected with the fire-room and used in the manipulation of the boilers.

When the boilers are to be built by contract specifications are written, giving such instructions regarding the construction of the boiler as have not been illustrated with sufficient clearness in the drawings; it is necessary to specify distinctly the quality of the material to be used for different parts of the boiler, and the workmanship. Specimens of specifications are appended to this chapter.

The sheets are ordered from the manufacturer as nearly as possible of the shape and size required, proper allowances being made for laps and flanging and for planing the sides and ends.

A list is made of all sheets required, showing their dimensions, their weight, and the part of the boiler for which they are to be used ; a sketch, showing the exact shape and dimensions of all sheets that are not rectangular or circular, accompanies this list. In laying off the size of the sheets care must be taken to get as few seams as possible in contact with the fire, and to get them in the most convenient position for riveting and accessible for calking. The greatest tensile stress on all sheets must come in the direction of the fibre ; therefore cylindrical shells must be made with the fibre of the sheets running around them. Since the joints are the weakest and most troublesome parts of a boiler, it is advantageous, with regard to economy and strength, to make the sheets as large as possible.

9. Specifications for Boilers for U. S. Steam-sloop "Lackawanna," reference being had to the accompanying Drawings (Plates VI. and VII.)—There are to be three vertical tubular boilers, containing an aggregate grate-surface of 273 square feet and a total heating-surface of 8,980 square feet. The two main boilers are to be made right and left ; the one for the starboard side of the ship is to be 25 feet long and to have seven furnaces ; the opposite boiler is to be 21 feet 6 inches long and to have six furnaces ; the other, or auxiliary, boiler is to have one furnace, and is to be placed aft of the six-furnace boiler, and is to be 4 feet long.

Extreme height of boilers, exclusive of steam-drums, to be 9 feet 5 inches.

Extreme depth of boilers at furnaces, 10 feet 3 inches ; at top of shell, 11 feet 9 inches.

Each main boiler is to have a steam-drum extending 2 feet 9 inches above the top of shell. Each furnace is to be made with an independent combustion-chamber, which communicates through a tube-box containing 310 tubes with a front-connection, and unites with the others in a common uptake which is to have a calorimeter equal to that of all the tube-boxes.

Material.—All the parts of the boilers, except the tubes, are to be made of the very best American charcoal-iron.

Water-legs.—The boilers are to be made with water-legs, which are to enclose water-spaces 6 inches wide, including the thickness of metal ; they are to be made of the best flange-iron $\frac{7}{16}$ inch thick ; the bottom plate of each to be of one sheet, and to be made to lap outside the vertical plates forming the leg.

Shell of Boilers.—The bottom of shell at back part of boilers to be $\frac{7}{16}$ inch thick

and to extend above the turn to the sides. All other parts of the shell to be $\frac{5}{16}$ inch thick.

Furnaces.—Each furnace is to be 3 feet wide and 6 feet 6 inches long on the grates. The crown of each furnace is to be $\frac{3}{8}$ inch thick, and made of one sheet extending on each side below the grate-bars.

Connections and Tube-boxes.—The front-heads of furnaces and back-heads of back-connections are to be made of the best flange-iron $\frac{3}{8}$ inch thick; sides and top of back-connections $\frac{3}{8}$ inch thick, and bottom $\frac{7}{16}$ inch thick; the sides of tube-boxes $\frac{3}{8}$ inch thick; front-connections and uptake to be $\frac{3}{8}$ inch thick, to be of the best flange-iron.

Tube-sheets to be $\frac{1}{2}$ inch thick, of the best flange-iron. Water-spaces between the tube-boxes, front and back connections, to be 6 inches wide, including the thickness of metal.

The tubes are to be made of drawn brass, to be 2 inches external diameter and $33\frac{1}{4}$ inches long, and to be of No. 13 wire-gauge thickness.

Bracing.—The top and side of the shell of boiler above the tube-boxes to be stiffened by T-iron $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{3}{8}''$, placed every 12 inches, to which the braces are to be attached. Each flange of the T-iron is to be riveted to the shell every four (4) inches, and the rivets so placed as to alternate with each other. The braces are to be not over 12 inches apart, and to be coupled to diagonals, which are to be attached to the T-iron by bolts and nuts placed not over 12 inches between centres; braces to be $1\frac{1}{2}''$ diameter; diagonals to be double, of rectangular section $2'' \times \frac{5}{8}''$, and secured by bolts $1\frac{1}{4}''$ diameter. All flat spaces not stiffened by T-iron to be braced every 8 inches by socket-bolts of $1''$ diameter. Crown of furnaces to be thoroughly braced. Care is to be taken that the strength of bracing herein specified is to be carried out in all the diagonals, angle and T-irons, and their rivets and attachments, and in the welding, so that no parts are left more weakly braced than herein specified.

Riveting.—All seams not in contact with the fire to be double-riveted, and the rivets to be staggered.

Seams.—All seams to be calked on both sides when practicable, and no acids are to be used in forming them, nor any fitting pieces to be inserted.

Manholes.—Each boiler is to be provided with two manholes, $12'' \times 15''$ diameter, opening into the steam-room, one on each end of the main boilers, placed on the front side, and one in the front side of the auxiliary boiler.

Manholes, $12'' \times 15''$ diameter, will also be placed in the spandrels of the furnaces. Each manhole is to have around it on the inside a wrought-iron band, $\frac{3}{4}$ inch thick and

4 inches wide, double-riveted to the shell; inner row of rivets countersunk flush on both sides.

Manhole-covers.—The manholes to be provided with cast-iron covers, the joints of which are to be faced. The plates to be secured in place by wrought-iron cross-bars and bolts.

Handholes.—Each boiler is to have a handhole near the bottom of each leg at each end. Openings to be elliptical, with diameters of 3″ and 5″, and to be fitted with cast-iron plates, the joints of which are to be faced; bars, bolts, and rivets to be of wrought-iron.

The *Furnace-doors* and *Grate-bars* are to be furnished by the Government and to be properly fitted in place by the contractors.

Uptake-doors to be of wrought-iron, double-shell, and fitted with the proper hinges and latches, and to be filled with some approved non-conducting substance.

Ashpit-doors to be made of wrought-iron, $\frac{1}{8}$″ thick, with a flange $\frac{3}{4}$″ deep all around; to be well fitted for closing the ashpit, and arranged to hang by proper hooks to the uptake-doors when not in use.

10. Extract from Specifications for Engines of U. S. S. "Miantonomoh." (Plate VIII.)

Boilers and Attachments.—There are to be six return horizontal tubular boilers, placed forward of the engines, three on each side of the vessel, with the fire-room running fore and aft between them.

There is to be one chimney in vertical line over the keel, connecting with an uptake common to all the boilers.

The boilers are to be constructed of the best American charcoal flange-iron; all seams not in contact with the fire to be double-riveted. All the plates to be planed on the edges, the seams to be butt-jointed and covered with butt-straps of the same thickness as the plates with which they are in contact; all to be calked perfectly tight.

Each boiler is to be 12 feet external diameter and 10 feet in length, to have three cylindrical furnaces, 36 inches internal diameter, projecting 6 inches from front of boiler and extending to the back-connections.

Grate-surface.—Each furnace is to have a grate 36 inches wide and 84 inches long, or 21 square feet, aggregating 378 square feet in the six boilers.

Grate-bars to be double, in two lengths, $\frac{5}{8}$ inch apart, $\frac{3}{4}$ inch thick at top, $\frac{5}{16}$ inch at bottom, 4 inches deep at centre and 2 inches at ends.

Tubes.—Each boiler is to contain 197 drawn-brass tubes, 3 inches external diameter and 7 feet 3 inches long, No. 12 wire-gauge thickness.

Shell to be formed of plates $\frac{3}{4}$ inch thick; joints to be butted and strapped, and to be double-riveted each side of seams.

Heads.—The front and back heads to be $\frac{1}{2}$ inch thick, each composed of three plates making two horizontal joints, planed and butted; the straps to be $\frac{1}{2}$ inch thick and $9\frac{1}{2}$ inches wide, double-riveted each side.

Bracing.—The heads will be braced by rods, $1\frac{5}{8}$ inches in diameter, placed 12 inches between centres; the ends of rods to be made with jaws and coupled to stay-plates at each end by a wrought-iron bolt $1\frac{3}{8}$ inches in diameter. Stay-plates to be of the best iron, $\frac{5}{8}$ inch thick, and secured to boiler by a flange $2\frac{1}{2}$ inches wide and an angle-iron 3 by $3\frac{1}{2}$ inches. The stay-plates to be made with lugs 6 inches in diameter, leaving openings for the removal of the braces.

Furnaces.—The furnaces are to be made of the very best iron, $\frac{1}{2}$ inch thick. Each furnace is to be formed of three cylindrical sections, 36 inches internal diameter, butted and strapped, flanged on the ends, and riveted to each other with a welt, $\frac{1}{2}$ inch thick, between them. The furnaces to be double-riveted at their junctions with the front-heads.

The *Back-connections* are to be 27 inches deep and made as shown in the drawings; side and back plates to be of $\frac{1}{2}$-inch iron. The side and back heads to be stayed by socket-rivets 1 inch in diameter and spaced not over 7 inches from centre to centre.

The *Tube-sheets* are to be $\frac{1}{2}$ inch thick. The centre tube-sheets are to be accurately drilled for 63 tubes; the two outer tube-sheets to be accurately drilled for 67 tubes in each. The tubes are to be spaced horizontally and vertically 4 inches between centres.

Manholes.—There are to be manholes $9\frac{1}{2}$ inches by 13 inches in the front-head of each boiler in the outer spandrels above the furnaces, and in the lower spandrels between the furnaces, and a manhole 11 by 15 inches in the space above the centre furnace. Each manhole to have around it on the outside a wrought-iron band, 1 inch thick and 4 inches wide, double-riveted to shell; inner row of rivets countersunk flush on both sides. Manholes to be closed with cast-iron plates and secured with double wrought-iron cross-bars and bolts.

The *Front-connections* and *Uptakes* are to be made with double shells of wrought-iron, built on angle-iron frames; the angle-iron to be $2\frac{1}{4}$ inches by $1\frac{1}{2}$ inches; the inside and outside shells to be made of iron weighing respectively 5 lbs. and $3\frac{8}{10}$ lbs. per square foot. The space between shells to be filled with some non-conducting material. The uptake at the connection with the smoke-pipe to be 8 feet 3 inches in diameter. The doors are to be made of wrought-iron, double shell, and fitted with the proper hinges

and catches ; outside shell $\frac{1}{4}$ inch thick, flanged 1 inch deep ; inside shell $\frac{1}{4}$ inch thick, flanges $2\frac{1}{4}$ inches deep.

Furnace-fronts to be made with a cast-iron frame covered with wrought-iron plates $\frac{3}{8}$ inch thick, and having openings 20 by $13\frac{1}{2}$ inches for furnace-doors. The outside plates to have twelve air-holes $1\frac{1}{8}$ inches in diameter, and the inside plates to be perforated with 250 holes $\frac{1}{4}$ inch in diameter.

The *Furnace-doors* to be made with wrought-iron fronts $\frac{1}{4}$ inch thick and flanged 1 inch deep ; each to be fitted with a perforated wrought-iron back and the necessary hinges and latches of wrought-iron.

The *Ashpit-doors* to be made of wrought-iron $\frac{1}{8}$ inch thick, flanged 1 inch deep ; to be well fitted to close the ashpits, and arranged to hang by proper hooks on uptake-doors when not in use.

Saddles.—Each boiler is to rest on two saddles made of wrought-iron and properly secured to the ship. The boilers to be secured to the saddles by suitable wrought-iron straps and bolts. The bolts for straps (which pass *through* the shell) to be turned and snugly fitted into reamed holes.

Steam-drums.—There are to be two steam-drums on each side, placed in the spandrels above the boilers, each to be 42 inches in diameter and 8 feet 6 inches long. Shells to be $\frac{3}{8}$ inch thick, heads $\frac{1}{2}$ inch thick. Each head to be braced by ten gussets equally divided on the shell ; gussets to be of $\frac{3}{8}$-inch iron, extending 30 inches on the shell and 11 inches on the head, and securely riveted to shell and head by angle-iron $2\frac{1}{2}$ by $2\frac{1}{2}$ inches.

Two *Superheating Steam-pipes*, 15 inches in diameter, made of the best boiler-plate $\frac{34}{100}$ inch thick, are to be placed within each front-connection, and united with each other at forward ends and to steam-drums placed in the spandrels above the boilers. All to be of the best American charcoal-iron.

Safety-valves.—Each boiler and superheating-pipe is to have a safety-valve $5\frac{1}{2}$ inches in diameter, fitted with the proper weights and levers for a pressure of 80 lbs. of steam. The chests to be of cast-iron, the valves and seats of composition ; the valves to be connected to copper pipes leading to the chimney.

Dry-pipes.—Each boiler is to have a sheet-brass dry-pipe thoroughly tinned and of an internal diameter of 7 inches ; the pipe to be placed as high as possible and extend nearly the length of the boiler ; the top, for a distance of $3\frac{1}{2}$ feet on either side of the centre of its length, to have holes $\frac{3}{8}$ inch in diameter drilled equally distant ; the aggregate area to be double the cross-section of the pipe.

Stop-valves.—Each boiler is to have a composition stop-valve placed on the back-

head near the top, and united with the boiler and dry-pipe by flanges $11\frac{1}{2}$ inches in diameter and $\frac{13}{16}$ inch thick; the chest to be not less than $\frac{5}{16}$ inch thick. The valve is to be 6 inches in diameter, and fitted with a screw-stem made to turn independently of the valve, and work in a composition nut supported by wrought-iron studs on the covers; the valve to be operated by a composition hand-wheel 12 inches in diameter.

Pipes.—The stop-valves are to be connected with the steam-drums by copper pipes 6 inches internal diameter and No. 16 Birmingham-gauge thickness; the pipes to have composition flanges, $11\frac{1}{2}$ inches in diameter and $\frac{13}{16}$ inch thick, properly riveted and brazed on.

Main Stop-valves.—There are to be two main steam stop-valves placed between the boilers and the engines; they are to be connected with the superheating-pipes and each other by pipes 12 inches in diameter, and arranged to close the steam from either the port or starboard boilers while the others are in use. The chests are to be of cast-iron $\frac{7}{8}$ inch thick, flanges $1\frac{3}{8}$ inches thick. They are to be fitted with composition valves and seats, the valves to be 12 inches in diameter, and are to have screw-stems made to turn independently of the valves and work in composition nuts supported by wrought-iron studs on the covers; the valves to be operated by composition hand-wheels 20 inches in diameter.

The *Main Steam-pipes* are to be of copper; three sections to be 12 inches in diameter and of No. 11 Birmingham-gauge thickness, two sections of 10 inches diameter and No. 14 Birmingham-gauge thickness; the sections connecting with the throttle-valves to be 9 inches in diameter and No. 14 Birmingham-gauge thickness; the several sections to be united to each other and the valves by composition flanges $\frac{7}{8}$ inch thick, properly riveted and brazed to the pipes. All the steam-pipes to be heavily tinned inside and out.

Bleeding-valve and Pipe.—There is to be a copper pipe, with stop-valve, of 4 inches in diameter, leading from the steam-pipe to the top of the condenser for bleeder.

Check and Blow Valves.—Each boiler is to have a check feed-valve, $2\frac{1}{2}$ inches in diameter, enclosed in a chest having two stop-valves of the same diameter, that may be closed from the boiler and feed-pipe; the valve and chest to be of brass and made with flanges $6\frac{1}{2}$ inches in diameter, $\frac{5}{8}$ inch thick, for connecting with feed-pipes and boilers. Each boiler is to have a bottom blow-valve of brass $2\frac{1}{2}$ inches in diameter, also a surface blow-valve 2 inches in diameter, all connected by suitable pipes to the sea-valves on the ship.

The *Main Feed* and *Blow Pipes* to be made in sections not exceeding 12 feet in length, and are to be of drawn-brass tubes, $3\frac{1}{2}$ inches inside diameter, of No. 8 Birming-

ham-gauge thickness; the branches to be 3 inches inside diameter, of No. 9 Birmingham gauge; the pipes to be fitted with composition flanges and elbows for uniting the sections, and are to be expanded in and sweated to them; the interior of pipes to be well tinned.

Gauge-cocks.—Each boiler is to have a combination gauge, which shall include a glass tube of 18 inches exposed length, and four cocks placed 6 inches apart, also drip-pan and pipe; the lowest cock to line with the bottom of glass tube, and placed to show the level of the water at the highest heating-surface.

Salinometers.—There are to be six of Fithian's salinometer-pots, fitted in such a manner as to be easily accessible.

Steam-whistle.—A large, finished steam-whistle of brass is to be conveniently placed above deck, with copper pipe and cock connecting to boilers.

Test.—Before being placed in the vessel all the boilers are to be subjected to a pressure of 120 lbs. to the square inch, which is to be obtained by filling the boilers quite full of water and lighting a fire in the furnaces, producing the pressure by the expansion of the water. The boilers, after completion, to be painted inside and out with two coats of brown zinc-paint.

Covering for Boilers.—After the boilers are in the vessel the entire shell and backs of the same are to be covered with a casing of galvanized iron, enclosing an air-space of 1½ inches between the boilers and casing; the sections of the casing to be substantially connected with each other, and in such a manner that they may easily be removed and replaced, and the joints made perfectly air-tight. The casing to be made with suitable openings and covers over man and handholes and braces required to be removed from the outside. The casing to be covered with two coats of brown zinc-paint.

Ventilators 18 inches in diameter are to fitted for the fire-room; they will extend below the deck to within 8 feet of the fire-room floor, and to be bell-mouthed at lower end. The portion above deck will be secured to deck by screwed eye-bolts passing through a flange and tapped into the rings around the holes through deck-plating; they are to have movable hoods, capable of being worked from fire-room, and will be made of iron No. 11 wire-gauge thick. The forward ventilators are to be arranged for hoisting ashes through them from deck by means of blocks and pulleys; to be strengthened with six strips of bar-iron placed vertically in the interior. These ventilators to have a side-door for passing the ash-buckets through.

11. Specification of Boilers (Iron Shells) for Vessels of the English Navy.—Specification of certain particulars to be strictly observed in the construction of ____ set of marine boilers, with superheaters, of the collective indicated power

of ____ horses, suitable for vessels of the ________ class. They are to be delivered complete by the ________, 18__.

Boilers.—The boilers to be tubular, capable of carrying steam of ____ lbs. to the square inch, and to be proved by water-pressure to ____ to the square inch.

They are to be constructed in ____ separate parts, in accordance with the form and dimensions shown upon the accompanying tracing.

Furnaces.—There are to be ____ furnaces of the dimensions given on the tracing. To admit of bituminous coal as well as Welsh coal being burned effectively, perforated bridges are to be fitted, with means of regulating the supply of air through them to any degree of opening. The aggregate area of the perforations in the bridges to be not less than 3 square inches per square foot of fire-grate for admission of air to the combustion-chambers. The furnace-doors to be fitted with internal and external screen-plates, perforated with a few holes to keep the doors cool, and means to be provided for keeping them open in a sea-way.

The furnace-bars to be of wrought-iron, $3\frac{1}{2}$ inches deep by $1\frac{1}{4}$ inches wide, and to be made in ____ lengths. The length of fire-grate to be ____ feet ____ inches.

Boiler-plates, etc.—The tube-plates, the uptakes, the furnaces, and the combustion-chambers, with the angle-iron and rivets in these parts, and all screwed stays, are to be of Low Moor, Bowling, or Farnley iron, and all other parts of BB Staffordshire or other iron of equal quality. The minimum thickness of the boiler-plates to be as follows: tube-plates, ____ inch; uptakes and bottom of shells, ____ inch; bottoms of furnaces, ____ inch; upper and lower parts of fronts, ____ inch; and all other parts, ____ inch. The bottom plates of the shells to be double-riveted throughout. All the plates of the boilers to be lap-jointed, excepting the lower parts of the fronts, which are to be lap-welded.

Tests of Plates.—All plates (with the exception of Low Moor, Bowling, or Farnley plates, which will not be tested) must be capable of standing the following tests:

Tensile strain per square inch.

Lengthways	21 tons.
Crossways	18 "

Forge-test (hot).

Plates to admit of being bent hot, without fracture, to the following angles:

Lengthways of the grain	125 degrees.
Across	100 "

Forge-test (cold).

Plates to admit of being bent cold, without fracture, to the following angles:

Thickness of plate.	With the grain.	Across the grain.
	Through an angle of	Through an angle of
1 inch.	15 degrees.	5 degrees.
$\frac{15}{16}$ "	15 "	5 "
$\frac{7}{8}$ "	20 "	$7\frac{1}{2}$ "
$\frac{13}{16}$ "	20 "	$7\frac{1}{2}$ "
$\frac{3}{4}$ "	$22\frac{1}{2}$ "	10 "
$\frac{11}{16}$ "	25 "	10 "
$\frac{5}{8}$ "	$27\frac{1}{2}$ "	$12\frac{1}{2}$ "
$\frac{9}{16}$ "	30 "	$12\frac{1}{2}$ "
$\frac{1}{2}$ "	35 "	15 "
$\frac{7}{16}$ "	$42\frac{1}{2}$ "	$17\frac{1}{2}$ "
$\frac{3}{8}$ "	50 "	20 "
$\frac{5}{16}$ "	60 "	25 "
$\frac{1}{4}$ "	70 "	30 "

Tests of Tee-irons and Angle-irons.—Tensile strain per square inch with the grain, for every description, 21 tons.

The ductility and other qualities of the iron should be such as to admit of its being bent hot and cold in the following manner, without fracture:

ANGLE-IRON.

Forge-test (hot).

Angle-iron should be tested hot by being bent thus:

Fig. 10.*a*

Fig. 11.*a*

Fig. 12.*a*

and also by being flattened thus:

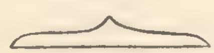


Fig. 13.*a*

and the end bent over thus:

Fig. 14.*a*

Forge-test (cold).

Angle-iron should also be notched and broken across cold to show the quality of the iron; and one flange should be cut off and bent cold, thus:

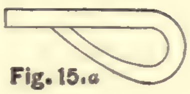


Fig. 15.a

TEE-IRON.

Forge-test (hot).

Tee-iron should be tested hot by being bent thus ·

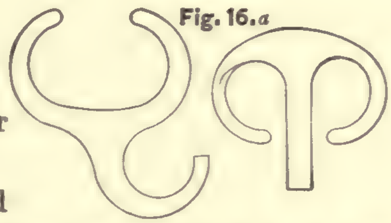


Fig. 16.a

Forge-test (cold).

The cold test for tee-iron should be similar to that for angle-iron.

Tests of Stays and Rivets.—Samples of angle, tee, and bar iron for testing are to be selected from quantities of two tons or portion of two tons weight.

Bar-stays, Yorkshire iron screwed stays, and rivets are to be capable of standing a tensile strain per square inch of 21 tons.

Boiler-tubes.—The tubes are to be of brass, solid-drawn (with the exception of the stay tubes, which are to be of Low Moor, Bowling, or Farnley iron), and are to contain not less than 68 per cent. of best selected copper.

The total number of tubes (including stay-tubes) is to be _____, their mean thickness to be not less than No. _____ wire gauge, their external diameter to be not less than .... inches, and their length, outside the tube-plates, to be _____ feet _____ inches. The stay-tubes are to be not less than _____ inch in thickness.

Test of Tubes.—Samples of tubes, weighing at least 10 lbs., selected by the boiler overseer, are to be forwarded by the contractors to Portsmouth Dockyard, there to be subjected to such tests as their Lordships may direct. Each of the tubes is to be tested by water-pressure separately to 300 lbs. per square inch in the presence of the boiler overseer.

Manholes and Mudholes of Boilers.—In the manufacture of the boilers care is to be taken to have sufficient room for manholes for the purpose of cleaning and repairing the furnaces. All manholes and mudholes of the boilers to have stiffening-rings. The doors to be of wrought-iron, and to be placed on the inside of the boilers. The manhole-frames on the tops of the boilers to be raised sufficiently to clear the lagging of the boilers.

Stays of Boilers.—The stays are to be arranged on an approved plan so as to admit

of easy access to the internal parts of the boilers. Tee-irons to be attached to the shells of the boilers for the purpose of securing the long stays; the rivets or bolts for securing the stays to be at least 25 per cent. stronger than the stays, and all holes for such rivets or bolts to be drilled. Palm-stays are to be forged from the solid where practicable. The screwed stays to be nutted on all flat surfaces. The maximum strain on the stays at the working pressure must not exceed 5,000 lbs. per square inch of section at the bottom of the thread.

Circulating-plates.—Circulating-plates are to be placed in proper positions to aid in the circulation of the water, for which detail drawings will be supplied to the contractor.

Zinc Blocks.—Zinc blocks as required are to be supplied and suspended in each boiler for the purpose of preventing corrosion. A tracing showing the proposed arrangement of the blocks to be submitted for approval.

Superheaters.—The superheaters to be of the form and dimensions shown upon the tracing, and to be proved to ...... lbs. to the square inch by water-pressure. The tubes are to be of wrought-iron, Low Moor, Bowling, or Farnley, and not less than ...... inch thick. Their length to be ...... feet ...... inches, their diameter to be ...... inches, and their total number ......

Drawings.—Before the work is put in hand detail drawings with figured dimensions of the boilers and superheaters are to be submitted for approval. The drawings are to be made on tracing-cloth, to a scale of not less than 1 inch to the foot, and are to give full particulars of the mode of staying the boilers and superheaters, and also full details of the furnace frames and doors, perforated bridges, etc. A duplicate of the approved drawings to be furnished for the guidance of the boiler overseer.

In General.—No holes, with the exception of the manholes and mudholes, are to be cut, but the positions of the stop and safety valves, as indicated on the tracing, are to be kept clear of stays and seams.

Dampers are to be fitted to the mouth of every ashpit, and external plates to be fixed to the fronts of the smoke-box doors. The threads of all nuts, screws, studs, etc., used in the construction of the boilers and superheaters are to agree with the threads used in Her Majesty's service. Particulars of these, together with any additional particulars relating to the perforated bridges, etc., will, on application, be furnished to the contractors.

Spare Gear.—The following articles of spare gear to be supplied:

Boiler-tubes.......................................one-tenth of the whole number.
Ferrules for boiler-tubes ....one set for the fire-box end of each boiler.
Stay-tubes with nuts complete...........................one set for each boiler.

Tap and die with suitable wrenches for stay-tubes.......................... .one each.
Superheater-tubes (including stay-tubes).
Furnace-bars......................................one-half set for each furnace.
Bearing-bars...sets for furnaces.
Screwed stays for boilers (one size larger than required when new) . . . the whole number.
Tap and die for the above, with suitable wrenches..........................one each.

Supervision.—The boilers and superheaters will be subject to the supervision of an overseer, who will be directed to attend on the premises of the contractors during the progress of the work, to examine the materials and workmanship used in their construction and to witness the prescribed tests. The extent of supervision is described on the attached paper extracted from Admiralty instructions to overseers.

Inspection.—The contract is to be executed in every respect to the satisfaction of the Controller of the Navy, who will, as he may see fit, appoint officers to inspect the work while in progress. The boilers and superheaters are to be proved by water-pressure in the presence of the inspecting officer, and means are to be provided for ascertaining their correct weight with fittings complete as supplied by the contractors. The weight of the water in the boilers, at a height of nine inches above the top of the tubes, also to be correctly ascertained. The boilers are not to be painted until they have been proved to the satisfaction of the inspecting officer.

Delivery.—After the boilers and superheaters have been proved they are to be well painted with red lead, and are then to be delivered complete, with fittings and spare gear, at ——————.

12. Material for six Boilers of U. S. S. "Nipsic." November, 1877. (Plate X.)

Letter of reference.	Number of sheets.	Dimensions in inches.	Weight in lbs.	Parts of boilers.
		Boiler-iron.		
	24	$170\frac{1}{2} \times 52 \times \frac{11}{16}$	41,568	Shell of boiler.
A	6	$119 \times 87 \times \frac{1}{2}$	7,040	Back-head.
B	6	$108 \times 73 \times \frac{9}{16}$	6,500	Back tube sheet.
C	6	$119 \times 86 \times \frac{9}{16}$	7,624	Front tube-sheet.
D	6	$110 \times 37\frac{1}{2} \times \frac{9}{16}$	2,813	Lower part of front head.
	12	$110 \times 33\frac{1}{2} \times \frac{7}{16}$	5,417	Furnaces.
	12	$110 \times 31 \times \frac{7}{16}$	5,012	"
	12	$110 \times 28 \times \frac{7}{16}$	4,527	"
	12	$120 \times 9\frac{1}{4} \times \frac{11}{16}$	2,564	Transverse shell butt-straps.
E	6	$120 \times \left\{\begin{matrix} 9\frac{1}{4} \\ \text{and} \\ 24\frac{1}{2} \end{matrix}\right\} \times \frac{11}{16}$	1,548	" "
	24	$57 \times 9\frac{3}{4} \times \frac{1}{2}$		
	12	$54 \times 9\frac{3}{4} \times \frac{1}{2}$	3,220	Longitudinal shell butt-straps.
	12	$30 \times 9\frac{3}{4} \times \frac{1}{2}$		
F	6	$110 \times 55 \times \frac{1}{2}$	3,991	Bottom of back-head.
	6	$100 \times 40 \times \frac{1}{2}$	3,360	Back-connection.
	6	$106 \times 58 \times \frac{1}{2}$	5,164	" "
	12	$75 \times 27\frac{1}{2} \times \frac{1}{2}$	3,465	" "
	6	$64 \times 42 \times \frac{3}{8}$	3,600	Butt-plates for front-head.
	12	$44 \times 36 \times \frac{3}{8}$		
	24	$128 \times 34\frac{1}{2} \times \frac{1}{2}$	14,847	Gussets.
	6	$106 \times 16 \times \frac{1}{2}$	1,425	"
	6	$94 \times 13\frac{1}{2} \times \frac{1}{2}$	1,066	"
	12	$96 \times 22 \times \frac{1}{2}$	3,548	"
G	12	$36\frac{1}{4} \times 20\frac{1}{2} \times \frac{3}{8}$	758	Furnace-front.
H	12	$34 \times 19\frac{1}{4} \times \frac{3}{8}$	667	" "
I	12	$36 \times 16 \times \frac{3}{16}$	274	Ashpit-doors.
J	24	$23\frac{1}{4} \times 16\frac{1}{4} \times \frac{1}{4}$	570	Furnace-doors.
	10	$86 \times 60 \times \frac{5}{16}$	4,500	Shell of steam-drums, gussets, etc.
a	8	37 (diam.) $\times \frac{3}{8}$	920	Heads of steam-drums.
		Total..............	135,988	

MATERIAL FOR SIX BOILERS OF U. S. S. "NIPSIC."—(*Continued.*)

Number of pieces.	Description.	Dimensions in inches.	Weight in lbs.	Parts of boilers.
45	Round bar-iron	$1\frac{1}{8}''$ diam. × $80''$ long	1,000	Stays.
50	" "	$1\frac{5}{8}''$ diam. × $60''$ long	1,753	"
38	" "	$1\frac{5}{8}''$ diam. × $80''$ long	1,774	"
	Flat bar-iron...	$\frac{3}{4}'' \times 2\frac{1}{4}''$	1,000	Braces.
	" " ...	$\frac{1}{2}'' \times 3''$	1,000	Furnaces.
	Angle-iron.....	$2\frac{1}{2}'' \times 2\frac{1}{2}''$	825	Gussets.
		Total............	7,352	
1,440	Rivets.	$\frac{7}{8}''$ diam. × $3\frac{3}{4}''$ long	1,340	Shell double straps.
2,535	"	$\frac{7}{8}''$ diam. × $3\frac{3}{8}''$ long	2,200	" " "
9,112	"	$\frac{7}{8}''$ diam. × $2\frac{7}{8}''$ long	7,100	Single straps and heads.
600	"	$\frac{7}{8}''$ diam. × $2\frac{3}{4}''$ long	450	Gussets and back-connections.
262	"	$\frac{7}{8}''$ diam. × $2\frac{3}{8}''$ long	180	Manhole-frames.
4,125	"	$\frac{3}{4}''$ diam. × $2\frac{3}{4}''$ long	2,100	Front-head strap, gussets, and furnace-rings.
2,250	"	$\frac{3}{4}''$ diam. × $2\frac{1}{2}''$ long	1,080	Gussets and furnace-front.
10,000	"	$\frac{3}{4}''$ diam. × $2\frac{3}{8}''$ long	4,650	Furnaces, back-connections, back-heads, manholes, and gussets.
3,525	"	$\frac{3}{4}''$ diam. × $2''$ long	1,480	Furnace-front and angle-iron on gussets.
		Total............	20,580	

NOTE.—Twenty-five per cent. is added to the amount actually required of each description of rivets.

13. List of Steel Plates for Boiler of Steamer "Lookout." (Plate X.)

Letter of reference.	Number of sheets.	Dimensions in inches.	Tensile strength in lbs. per sq. in.	Parts of boiler.
A	1	$95 \times 67 \times \frac{1}{2}$	60,000	Front-head, upper section.
a	1	$95 \times 67 \times \frac{7}{16}$	70,000	Back-head, " "
B	1	$89 \times 31 \times \frac{1}{2}$	60,000	Front-head, lower section.
b	1	$89 \times 31 \times \frac{7}{16}$	70,000	Back head, " "
c	1	$85 \times 52 \times \frac{1}{2}$	60,000	Back tube-sheet.
D	1	$85 \times 71 \times \frac{7}{16}$	60,000	Back-head, back connection.
	1	$192 \times 20 \times \frac{7}{16}$	60,000	Bottom and sides, back-connect'n.
	2	$265 \times 47\frac{1}{2} \times \frac{7}{16}$	70,000	Shell of boiler.
E	1	$60 \times 8 \times 42 \times \frac{1}{2}$	70,000	Longit'al outside strap, manhole.
F	1	$60 \times 8 \times 25 \times \frac{1}{2}$	70,000	" inside "
	1	$244 \times 8 \times \frac{7}{16}$	70,000	Circular strap.
	1	$92 \times 8 \times \frac{7}{16}$	70,000	Butt-strap, back-head.
	2	$92 \times 45 \times \frac{7}{16}$	60,000	Furnaces, front section.
	2	$92 \times 41 \times \frac{7}{16}$	60,000	" back section.
	4	$45 \times 5 \times \frac{7}{16}$	60,000	" straps.
	1	$55 \times 25 \times \frac{7}{16}$	70,000	Plate around manhole, front-head.
	2	$26 \times 24 \times \frac{7}{16}$	70,000	" " " "
	4	$24 \times 30 \times \frac{7}{16}$	70,000	Gussets and stay-plates.
	2	$18 \times 26 \times \frac{7}{16}$	70,000	" " "
	6	$27 \times 27 \times \frac{7}{16}$	70,000	" " "
G	1	65 (diam.) $\times \frac{7}{16}$	70,000	Head of steam-drum.
g	1	$65 \times 50\frac{1}{2} \times \frac{1}{2}$	60,000	Bottom " "
	1	$75 \times 73 \times \frac{7}{16}$	60,000	Uptake-pipe.
	1	$73 \times 5 \times \frac{7}{16}$	60,000	" strap.
	1	$171 \times 80 \times \frac{3}{8}$	70,000	Shell of drum.
	2	$80 \times 6\frac{1}{2} \times \frac{5}{16}$	70,000	Straps for drum.

LIST OF IRON PLATES, RIVETS, TUBES, ETC., FOR BOILER OF STEAMER "LOOKOUT."

Letter of reference.	Number.	Dimensions in inches.	
	1 sheet.	$90 \times 8 \times \frac{3}{8}$	
H	2 sheets.	$31 \times 17\frac{1}{2} \times \frac{3}{8}$	
I	2 "	$28 \times 16 \times \frac{3}{8}$	
K	2 "	$21\frac{1}{4} \times 15\frac{1}{4} \times \frac{1}{4}$	
L	2 "	$32 \times 14 \times \frac{3}{16}$	
	2 "	$82 \times 27 \times \frac{3}{16}$	
	2 "	$72 \times 24 \times \frac{1}{8}$	
	2 "	$54 \times 24 \times \frac{1}{8}$	
	2 "	$106 \times 3 \times \frac{1}{2}$	
	2 "	$124 \times 5\frac{1}{2} \times \frac{1}{4}$	
	1 sheet.	$72 \times 5\frac{1}{2} \times \frac{1}{4}$	
	2 angle-irons	$96 \times 1\frac{1}{2} \times 1\frac{1}{2}$	
	140 stay-bolts.	$1''$ diam. $\times 8\frac{1}{2}''$ long.	
	40 "	$1''$ " $\times 7\frac{1}{2}''$ "	
	30 rivets.	$\frac{13}{16}''$ " $\times 3\frac{1}{2}''$ "	
	170 "	$\frac{13}{16}''$ " $\times 3''$ "	
	280 "	$\frac{13}{16}''$ " $\times 2\frac{3}{4}''$ "	
	120 "	$\frac{13}{16}''$ " $\times 2\frac{5}{8}''$ "	
	50 "	$\frac{13}{16}''$ " $\times 2\frac{1}{2}''$ "	
	530 "	$\frac{13}{16}''$ " $\times 2\frac{3}{8}''$ "	
	1160 "	$\frac{13}{16}''$ " $\times 2\frac{1}{4}''$ "	
	500 "	$\frac{13}{16}''$ " $\times 2\frac{1}{8}''$ "	
	600 "	$\frac{3}{4}''$ " $\times 2\frac{1}{4}''$ "	
	400 "	$\frac{3}{4}''$ " $\times 2\frac{1}{8}''$ "	
	120 brass tubes.	$2\frac{1}{2}''$ outside diameter by 6 feet $2\frac{3}{8}$ inches long. No. 12 Birmingham gauge.	

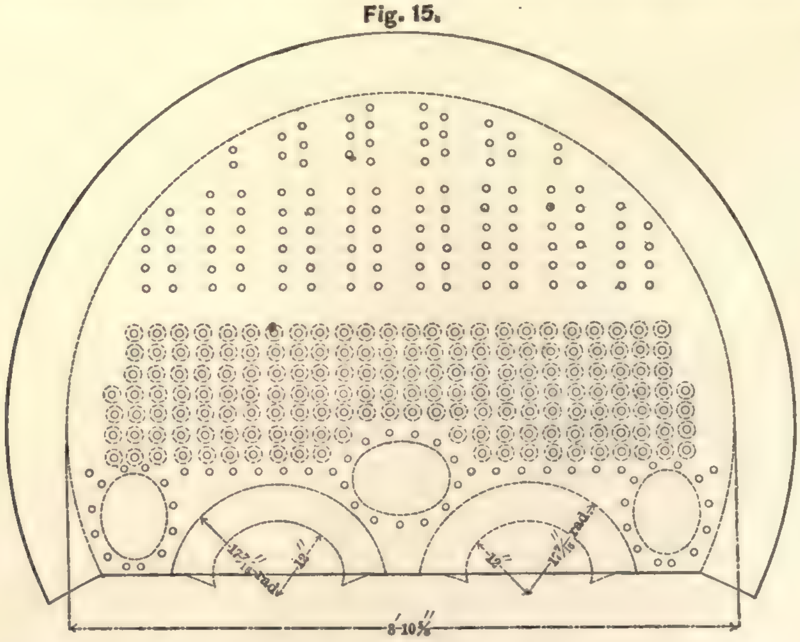
CHAPTER VIII.

LAYING-OFF, FLANGING, RIVETING, WELDING, ETC.

1. Laying-off.—The boiler-plates having been tested and examined as described in chapter v., they are made to pass, first with one side then with the other side upwards, between two cylindrical rollers, in order to level and flatten them and to smooth their surfaces.

The exact lines to which the plates are to be trimmed and cut and the flanges are to be turned, and the centres of all holes that are to be punched or drilled before the flanges are turned, are now laid-off on the plates and plainly marked by means of a centre-punch. The lines of curved surfaces are developed and laid down in full size on paper or on a board; in case several boilers are to be constructed from the same drawing it is well to make wooden or sheet-iron templates of irregularly-shaped plates, and

Fig. 15.



to mark the positions of holes and points which lie in the same straight lines on separate sticks, and to transfer them thence to the plates; the rivet-holes of seams are laid-

off by means of thin board templates having holes of the proper diameter, spaced as required. An intelligent and careful boiler-maker will lay-off in this manner the position of all lines and holes, except on flanges that are to be turned; frequently, however, the holes for stay-bolts are first laid-off and drilled only on one plate, and the corresponding holes in the opposite plate are marked off from these holes when the plates are fitted in position. Instead of using the centre-punch, the position of holes that are to be punched is often marked on the plate by means of a small round stick, called the *marker*, which, being dipped into some liquid whiting and passed through the holes of the template, leaves white circles on the plate.

Figure 15 represents the front-head and tube-sheet of the boilers of U. S. S. *Nipsic* (see Plate XII.), with the rivet-holes and centres of tube-holes punched, manholes and furnace-openings marked for cutting out, and the flanges for securing the shell and the furnace-tubes marked for turning.

In bending plates to the circular form the inner side is slightly compressed and the outer side is elongated, the neutral axis passing through the centre of the plate. Therefore the length of the plates for the shell of a cylindrical boiler with butt-joints must be equal to the outside diameter of the shell minus the thickness of the plate, multiplied by 3.1416, or $(d - t)\,\pi$.

When a cylindrical shell or flue is formed of alternate inner and outer rings with overlapping joints (see figure 16), the circumferential length of the plates forming the inner rings is found by multiplying double the thickness of the plates by 3.1416 and subtracting the product from the length of the outer rings. In laying-off the rivet-holes in the circumferential seams of these plates space the holes on the outer plates as required; the distance between the end holes of each seam of the inner plates must be equal to the distance between the corresponding holes of the outer plates, less the product of double the thickness of the plates multiplied by 3.1416; mark the end holes on the inner plates accordingly, and divide the distance between them equally, according to the number of rivets required for the seam.

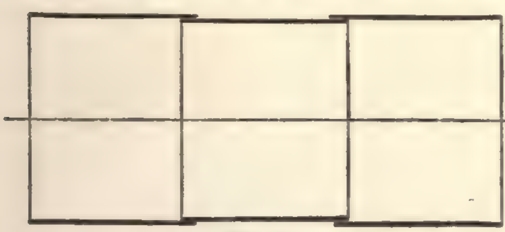


Fig. 16.

When the longitudinal seams of such cylinders are made with lap-joints the foregoing rules do not give the whole length of the plates, but the distance between the centre lines of the rivet-holes of the longitudinal seam, and a proper amount has to be added to the length of the plate as an allowance for lap.

Figure 17 represents the method of finding the form of plates for conical tubes.

Draw an elevation of the cone, *a b c d;* continue the side lines till they meet the centre line in *o;* from *o* as a centre draw with radii *o c* and *o a* two circles, and make the arcs *e h* and *f g* respectively equal to the required circumferential lengths of the two ends of the tube; draw the radial lines *e f* and *g h*. The figure *e f g h* represents the form of the plate required when the tube is to be butt-jointed. In case the tube is to be lap-jointed add the amount necessary for lap at each end of the plate, as indicated by the dotted lines, *i k* and *l m*, drawn parallel to *e f* and *g h* respectively.

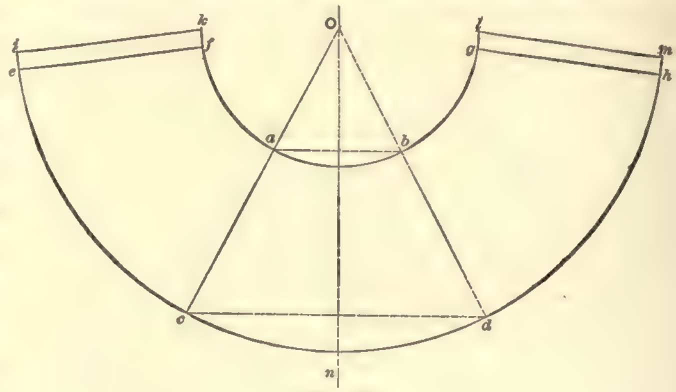


Fig. 17.

When a cylindrical shell or flue is formed of rings lapping telescopically, as in figure 18, each ring is slightly conical; the taper is, however, so small that the method

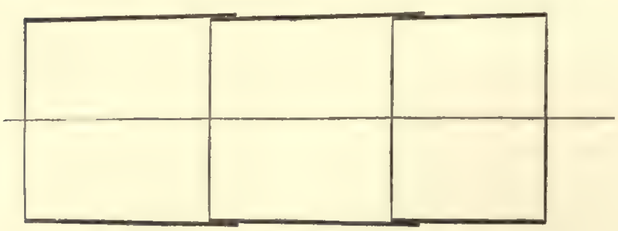


Fig. 18.

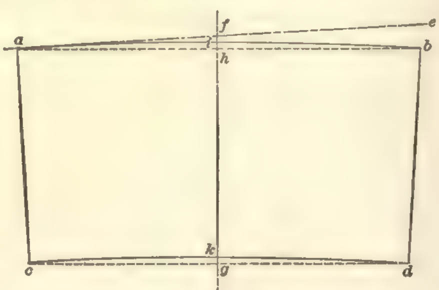


Fig. 19.

of finding the shape of the plate which was illustrated in figure 17 cannot be used practically, because the radius *o c* would be too long. The following convenient and sufficiently accurate method of finding the shape of such plates is given by Sexton (see figure 19):

Draw a centre line and mark on it the width of the plate, *g h;* draw perpendicular lines through the points *g* and *h;* find the circumferential lengths of the two sides of the plate by the rule given above; and from *h* and *g* respectively lay off one-half of these lengths on the perpendiculars on each side of the centre line, marking the points thus found *a*, *b*, *c*, *d*, and draw lines *a c* and *b d;* erect a perpendicular, *a e*, to line *a c* in *a*, cutting the centre line in *f;* $h\,i = \frac{f\,h}{2}$ is very nearly the versed sine of the arc forming the upper edge of the plate; draw a curve by means of a flexible batten

through the points *a*, *i*, *b*, and a similar one through *c*, *d*; then *a i b d k c* will be the form of the plate. The number of plates in the circumference of the tube does not affect this rule; the camber is constructed the same way, whether for one or for several plates.

When a wedge-shaped portion, or ungula, is cut off from a cylindrical shell, as in the boilers of U. S. S. *Nipsic* (see Plate XII.), the plates forming the cylindrical shell have

Fig. 20.

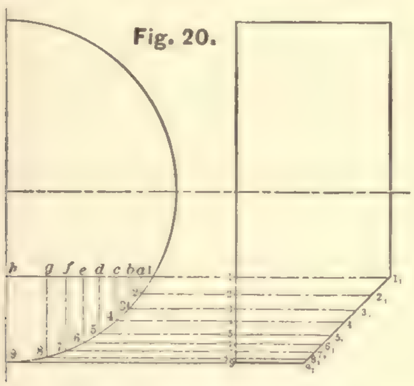
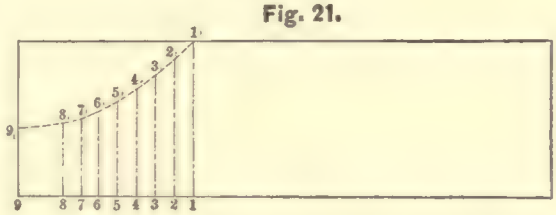
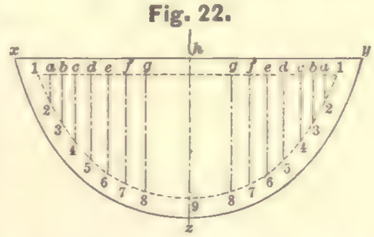


Fig. 21.



to be cut to a line 1_1—9_1 shown in figure 21. The method of laying-off this line is illustrated in figures 20 and 21. Mark any convenient number of divisions on the arc representing the portion of the shell cut away; project the points of these divisions on the side elevation of the shell, and draw the parallel horizontal lines 1—1_{11}, 2—2_{11}, 3—3_{11}, etc., through these divisions. Lay off the position of these divisions on the developed plate by measuring their distance on the arc from 9 and laying them off from the corresponding point 9 on the plate (figure 21), and erect perpendiculars at these points of division; measure the length of the lines 1—1_{11}, 2—2_{11}, etc., in the side elevation (figure 20), and lay them off on the perpendiculars erected in the corresponding points of figure 21. With a flexible batten draw a fair curve through the points thus found, which will be the required line.

Fig. 22.



To find the shape of the plate forming the slanting part of the back-head project the divisions 2, 3, 4, etc., of the arc in figure 20 on the horizontal line 1—*h*, and mark the points thus found *a*, *b*, *c*, etc. Lay off the distances *h*—1, *h*—*a*, *h*—*b*, etc., both ways from a centre line on a horizontal in figure 22, and mark the points thus found 1, *a*, *b*, *c*, etc.; draw perpendiculars through these points, making *h*—9, *g*—8, *f*—7, *e*—6, *d*—5, *c*—4, *b*—3, *a*—2, in figure 22, respectively equal in length to the slant lines 1_1—9_{11}, 1_1—8_{11},

1_1—7_{11}, 1_1—6_{11}, 1_1—5_{11}, 1_1—4_{11}, 1_1—3_{11}, 1_1—2_1 in the side elevation of figure 20. With a flexible batten draw a fair line through the points 1, 2, 3, 4, 5, 6, 7, 8, 9, 8, 7, 6, 5, 4, 3, 2, 1, in figure 22; then draw, at a distance depending on the width of the lap, the line $x\ y$ parallel to 1—1, and the curve $x\ z\ y$ equidistant from the curve 1—9—1.

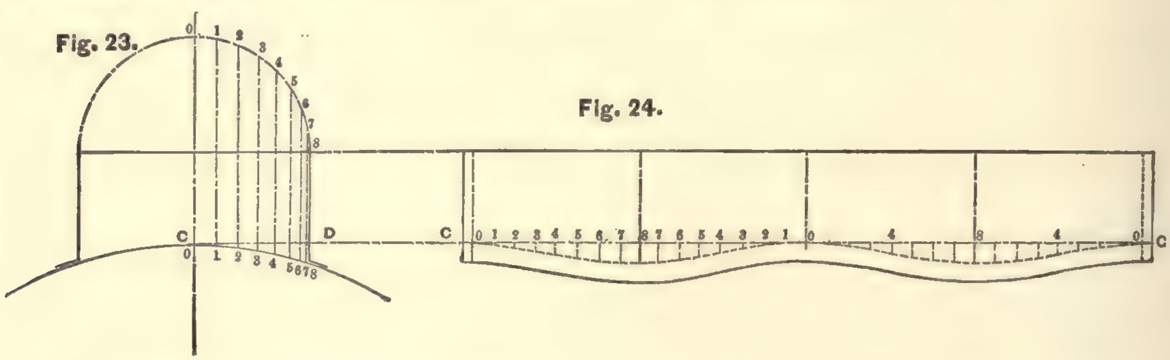


Fig. 23.

Fig. 24.

Figures 23 and 24 represent the method of laying-off a plate for the cylindrical shell of a steam-drum which is to be placed on the top of a cylindrical boiler. Figure 23 shows an elevation of the steam-drum and a portion of the boiler. Divide one-quarter of the circumference of the drum into a convenient number of equal parts, and from these divisions draw lines parallel with the sides of the steam-drum and touching the top of the boiler, as in figure 23. Find the length of the plate required by the rule given above for the development of cylindrical shells, and divide this length, exclusive of lap, into four equal parts (see figure 24), and each of these parts into the same number of parts as the quadrant in figure 23, numbering the corresponding points alike to avoid confusion. Along the plate (figure 24) draw a line, C C, representing the distance from the top of the boiler in the centre to the top of the steam-drum, and corresponding with the line C D in figure 23. Now mark on each subdivision the distance, corresponding to its number, from the line C D to the top of the boiler, as shown in figure 24, and through these points, by hand or by means of a flexible batten, draw a fair curve; parallel to this curve draw another at a distance corresponding to the width required for the flange.

When the diameter of the steam-drum does not exceed one-half of the diameter of the boiler the following shorter method is sufficiently accurate: Divide the plate into four equal parts and draw a line corresponding to the top of the boiler, as in the previous case; from this line draw one short line in the centre of each of the four divisions, corresponding to the points 4, 4, 4, 4 in figure 24. Call the centre of the plate and the two ends 0, and the remaining two lines 8; mark on the lines 8 the distance from the

level of the top of the boiler to the bottom of the side of the steam-drum, and on the lines 4 half that distance. Extend the trammel to such a radius that, by taking a continuation of the lines 8 as a centre, it will touch the marks on lines 8 and 4; and with the same radius describe arcs passing through the marks on lines 4 and the points 0 on the line C C.

Similar methods are employed in developing the lines of intersection of other curved surfaces.

2. Shearing and Planing.—After the holes and lines are laid-off and marked on the plate, the next operations are to punch or drill the holes and to cut the plates to the exact shape and size required. Manholes and similar openings and curved outlines are generally formed by punching a series of holes, running into each other, close to the line, the ragged edges being trimmed afterwards with a chisel. When the outline of the plate is straight it is either sheared or planed.

The shearing-machine commonly used for this purpose has a stationary and a movable steel cutter, the edges of which form an acute angle with each other, so that during the process of shearing the action is rendered gradual. The motion of the cutter is produced by means of an eccentric.

The process of shearing recommends itself through its simplicity, but it distresses the metal greatly, especially in the case of steel plates, and such edges as have to be calked have to be trimmed afterwards by hand to the proper bevel. On this account the edges of plates should be planed where careful work is required. Planing does not distress the metal; it produces a smooth edge, which can be cut at once to any bevel required for calking. For butt-joints the edges must be cut square and should always be planed.

3. Bending.—Sheets are bent to cylindrical shapes by passing them through the bending-rollers. The primitive bending-machine consists of two cast-iron rolls laid side by side, and a third roll, which is adjustable vertically, placed immediately over the hollow between the two lower rolls (see figure 25). In hand-power bending-machines set up on this plan the levers to turn the rolls are usually attached to one end of one of the bottom rolls and to the opposite end of the top roll.

In modern bending-machines the rolls are arranged as shown in figure 26. Two pinching-rolls are placed one directly over the other and geared together. The upper roll is adjusted to the thickness of the plate to be bent by two strong set-screws, and may be lifted out of the frame for the purpose of removing the bent plate. The third or bending roll is placed to one side of the lower roll, and may be moved, by means of a double hand-crank, bevel-wheels, and set-screws, past the lower roll toward

the upper one; this roll revolves by the friction of the plate against it. When this roll is down far enough to have its top level with the top of the lower pinching-roll a

Fig. 25.

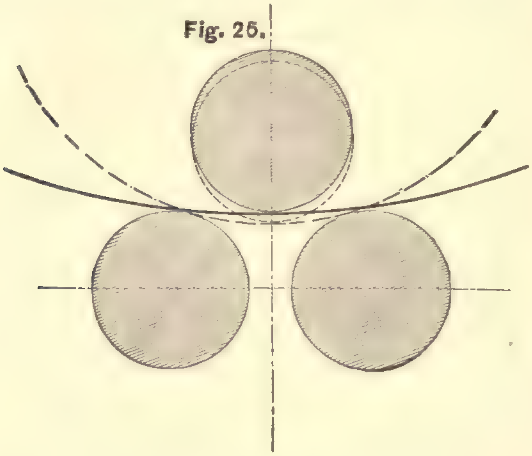


Fig. 26.

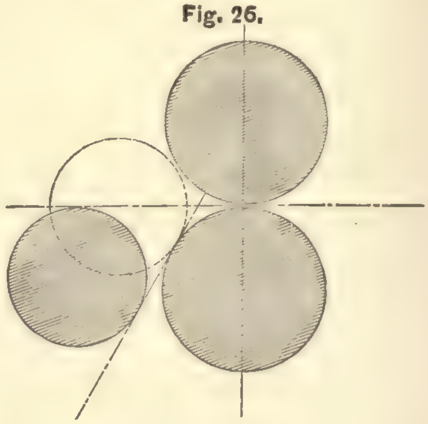


plate passing between the pinching-rolls will be flattened and levelled; but when the bending-roll is raised towards the upper roll the plate is bent to a circle, since each portion receives an equal curvature. By raising one end of the bending-roll higher than the other different degrees of curvature may be given to the two ends of the plate. Sometimes two bending-rolls are used, one on each side of the pinching-rolls; by this arrangement the plates can be bent nearer to the edge of the sheet than can be done with three rolls. A template is applied to the sheet from time to time during the process of bending, which is a gradual one, to see whether the proper curvature has been produced. The diameter of the rolls varies from eight to twelve inches.

4. Flanging.—When a plate is to be bent in a straight line to an obtuse angle it may be done cold by means of a set and a sledge-hammer. This process, however, as a rule, is objectionable, and should be avoided except in extreme cases. To produce other shapes cast-iron moulds of the required form are used. The outline of the bent portion is marked on the plate with centre-punch marks; the iron is then heated to redness, laid on the mould, and bent to shape by hammering. This process of bending the edge of a plate at an angle with the plate is called flanging. In flanging steel plates it is recommended to bend them as nearly as possible evenly along the whole length, as much as can be done in each heat. When a short circular bend is wanted in the middle of a long piece it is conveniently and accurately done by heating the piece in the middle and bending it over a ridge, the ends serving as levers.

Sexton gives the following practical instructions regarding flanging: "A plate

during the process of flanging will gain twice its thickness in length in each flange. Thus, suppose you want to flange a circular plate to have a 3-inch flange all round, and to be 3 feet diameter after being flanged and $\frac{3}{8}$ inch thick, you must not add twice the width of the flange to the diameter, making 3 feet 6 inches, but twice the width of the flange, less four times the thickness, making 3 feet $4\frac{1}{2}$ inches. In marking the plate line out the exact diameter you want it to be after being flanged, then allow the width of the flange, less twice the thickness; and, when flanged, the centre marks should be on the flange just where the curve joins the flat. The proper radius of the bend or root of a flange is twice and one-eighth the thickness of the plate for the outside curve. In heating the plate to be flanged, especially if it is a difficult one, confine your heat to as little as possible over the width of the flange, but take as long a heat as you can. To do this as it should be done make your fire the shape of the plate to be flanged. This is easily accomplished by bending a piece of thin iron and packing the coal (well wetted and mixed like mortar) up to it on the forge, or by adjusting a few fire-bricks to the required shape. Keep the centre of your fire always clean; do not allow dust or clinker to accumulate there, but let it consist of clean coke, broken small, and the harder the better. If possible, have a block or an anvil to fit the flange, and do not, on any account, flange on a block with sharp edges."

A flange turned at the circumference of a circular plate will be slightly thicker than the plate; but in forming flanges in the middle of a plate, like those for attaching the furnace-tubes of cylindrical boilers to the front-head and to the back tube-sheet, the metal has to be spread, and at the edges the flanges are much thinner than the plate. Such flanging tests the ductility of the iron severely. When the front-heads of cylindrical boilers are too large to be made of one plate it is well to let the seam run through the furnaces, as it is easier to form these partial circular flanges in the two plates than to turn a complete circular flange in one plate. In such a case an extra allowance of metal must be left at the corners of the flanges, or they must be spread out, as shown in figure 15, before the flanges are turned; because the metal will be drawn away from the edges in the process of flanging, and the flanges of the two plates would not meet in their whole width otherwise.

5. Punching.—The rivet-holes are either punched or drilled. During the former operation the plate rests on the table of the punching-machine, or it is slung in a chain and suspended from a crane, being held in position by several men, who shift it, after each hole is formed, so as to bring the stations of the successive holes under the punch. Slight deviations from the correct positions of the holes are almost unavoidable with this process, and, in order to avoid this source of error and secure greater rapidity in the

execution of the work, some machines are arranged to punch several holes at the same time, and are provided with a travelling-table, which moves after each stroke of the punches automatically through the proper distance. Devices for spacing the holes mechanically are of special value for cylindrical boiler-work, since the holes are punched before the sheets are bent by the rollers, and it is necessary to make an accurate allowance for the difference of circumference of the inner and outer sheets.

Punches are made of steel, and are generally cylindrical with a flat end (see figure

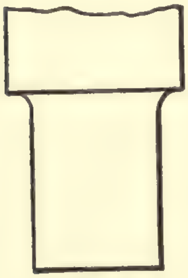


Fig. 27.

Fig. 28.

Fig. 29.

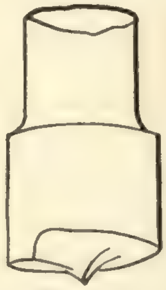


Fig. 30.

27). When a centre-punch is used to mark the stations of the holes a point is formed at the centre of the end of the punch, as shown in figure 28, in order to feel for the puncture. Reed says that punches distress the iron less when the ends are formed as shown in figure 29, instead of being flat. Others claim an equal advantage for punches with a slightly concave face, especially for punching large holes.

Figure 30 represents *Kennedy's helical punch.* "Its form may be explained by imagining the upper cutter of a shearing-machine being rolled upon itself so as to form a cylinder of which its long edge is the axis. The die being quite flat, it follows that the shearing action proceeds from the centre to the circumference, just as in a shearing-machine it travels from the deeper to the shallower end of the upper cutter." Results of experiments made at Crewe, England, on the tensile strength of samples of the same plate punched with Kennedy's spiral and ordinary punches respectively, showed an average of nine per cent. in favor of the former. Plates punched with both punches broke in every case through the hole of the ordinary punch.

It is usual to have the holes $\frac{1}{16}$ inch larger than the rivets, for $\frac{3}{4}$-inch rivets, in order to allow for their expansion when hot; it is evident, however, that the difference between the diameters of the hole and of the rivet should vary with the size of the rivet.

The hole in the die is made larger than the punch; for ordinary work the proportion of their respective diameters varies from 1 : 1.15 to 1 : 1.2. William Sellers & Co.,

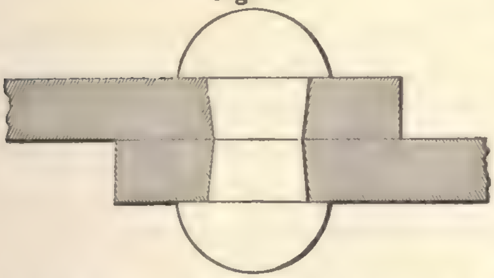
Philadelphia, use the following rule for proportioning the size of the die-hole: The diameter of the die-hole is equal to the diameter of the punch plus two-tenths the thickness of the plate ($D = d + 0.2\,t$). By making the die-hole larger than the punch a taper hole is produced in the plate, and the punching can be done with less expenditure of power and with less strain on the plate.

Daniel Adamson states that "the power required to punch a hole through a steel plate equal to a sectional inch of detruding area may be found by multiplying the maximum tensile strength per square inch by 0.74 of the same metal—the detruding area meaning the circumference of the punch multiplied by the thickness of the plate. This law may be depended upon both for soft and hard steels."

The sheets must always be punched from the "*faying*" surfaces—*i.e.*, the surfaces in contact; thus no burr or roughness is left around the holes to keep the sheets apart or necessitating time and labor for its removal; the holes are also better filled by hammering down the hot rivet, which assumes the form of two frusta of a cone joined at the small ends, and brings the sheets in closer contact by contraction in cooling (see figure 31).

Special attention has to be paid to this point in punching the rivet-holes in sheets that are intended for cylindrical shells and tubes, since the holes at the ends have to be punched from different sides, according to the style of joint used.

Fig. 31.



Numerous experiments have established the fact that the strength of plates is materially impaired by punching. A. C. Kirk, in a paper read before the Institution of Naval Architects in 1877, says: "The effect of the punch is clearly shown in the fracture by a portion highly crystalline on each side of the hole. This crystalline fracture around the hole is due to the bursting pressure exerted by the piece punched out, as it tends to spread out in diameter under the intense pressure of the punch. Under this strain the metal is compressed for a certain distance round the hole, and thus weakened." This zone of injured metal does not extend farther than $\frac{1}{8}$ inch from the hole, and the injurious effect of punching may be entirely removed by punching the holes somewhat smaller than the size required and reaming or drilling them out afterwards. Annealing after punching restores, likewise, to the strained metal its former strength and elasticity. In many establishments steel boiler-plates are always annealed after punching. The injurious effect is diminished by increasing the proportion of the diameter of the die-hole

to that of the punch; and it is much greater for steel, especially the harder qualities, than for iron.

The results arrived at by different experimenters vary greatly as to the amount of injury produced by punching, owing, no doubt, to differences of condition in the process and in the quality of the material. C. H. Haswell concludes from recent experiments that the resistance of riveted steel plates with the holes drilled is, according to the temper of the metal, from 18 to 25 per cent. greater than when they are punched. A. C. Kirk states that when the diameter of the holes is three times the thickness of the plate, or greater, the injurious effect of punching is inappreciable.

6. Drilling.—The practice of drilling the holes instead of punching them comes more and more into favor, because the metal is not injured by this process and the holes are more readily correctly spaced. It is necessary to remove the sharp edge or burr of the drilled hole carefully by slightly countersinking it; and when the holes have been drilled through two or more plates together the latter must always be taken apart for the purpose of removing the burr.

Fairbairn considered the exactly cylindrical, parallel, and smooth drilled holes not well adapted to rivets. Besides, punching saves about one-fourth the time and labor as compared with drilling as ordinarily practised.

Special machinery has been introduced of late for drilling the holes in the various parts of boilers. In *Harvey's Boiler-drilling Machine* the cylindrical shell of a boiler is placed vertically upon a central circular turn-table. The machine is provided with three drilling head-stocks, which travel on an outer rail around the boiler, and each one of which can drill one-sixth of the circumference of the boiler without moving the latter. Each head-stock is provided with a vertical traverse for drilling the longitudinal seams.

A very convenient arrangement for drilling the holes of boilers was designed by Chief-Engineer H. Newell, U.S.N., who describes the method pursued in building a set of cylindrical boilers, 8 feet in diameter, for the U. S. S. *Galena*, at the Navy-Yard, Norfolk, Va., in a report transmitted to the U. S. Navy Department, in the following words:

"Figure 2 [Plate XIV.] represents the method of drilling the circumferential butt-straps, which join the two sections of the boiler-shell. A is a shaft of wrought-iron, on which slides and revolves easily the arm B, on one end of which is attached a Laubach Patent Portable Drill, C, the weight of which is counterbalanced at the other end by the weight E, made in halves, secured to the arm by a bolt and nut. The shaft is adjusted and maintained central to the shell by the tripod D, D, D, clamped tightly to the

shaft by three bolts near the centre, and to the shell by set-screws, as shown. The back end of the shaft is supported by a block of wood bolted to the back-head through the holes intended for socket-bolts. The power is communicated to the drill from any convenient distance and at any angle, through a telescopic shaft and universal couplings, from a counter-shaft (furnished with the patent drill) driven from the fly-wheel of a small Sewell steam-pump, which is secured on blocks and can be transported to any part of the boiler-shop, steam being led to it through a rubber hose and the exhaust steam carried away through another hose.

"The arm B is moved from hole to hole radially and fore and aft, and secured in position each time by a set-screw and gib in the boss. With this machine the entire circumference is drilled without once moving the boiler, and as many as 360 holes $\frac{15}{16}''$ diameter have been drilled by it, through iron $\frac{9}{16}''$ thick, in one working day of ten hours. The drills are driven at about 250 revolutions per minute. This speed is rendered possible by, and the great efficiency of the machine is dependent on, the use of a fine stream of soapy water directed with considerable force against the point of the drill, which is kept cool by the rapid evaporation of the spray directed upon it. The water is supplied from a barrel placed about 30 or 40 feet above the work, and conducted to the drill by a rubber hose with a fine nozzle at the end. This height gives a sufficient head to cause the fine stream of water to strike the point of the drill with considerable force and to reach it in a hole of any depth, and it is immaterial whether the drilling is in an upward or downward direction. With the use of oil it would be necessary to move the boiler-shell around so as to bring the drill always in a downward direction.

"Figure 1 shows the arrangement for drilling the furnace from the inside, and also the arrangement for drilling the flanges of the boiler-heads from the outside. In the former the shaft F, having a flange on one end, is supported at each end by a cast-iron tripod, H, H, H, adjusted in the furnace by means of a set-screw at the end of each arm. The shaft is at liberty to revolve and to move fore and aft in the bosses of the tripods in order to adjust the point of the drill to the holes in the template, and is held securely, while drilling, by a set-screw in the boss. The Laubach Patent Drill is bolted directly to the flange at the end of the shaft F, and is the same as in the last machine, excepting that the limited space makes it necessary to use a shorter feed-screw. With the outside drilling-machine the same shaft A, tripod D, D, D, and centre part of arm B are used as in figure 2 [Plate XIV.]; one end of the arm B is lengthened by bolting to it a bar of T-iron, bent to the form shown, in order to bring the drill over the edge of the boiler, and also to clear the projection of the furnace-ends. The tripod, being in three pieces, is passed through the manhole separately and bolted together in place.

The back end of the shaft is supported by a small casting, G, held in position by a bolt passed through holes in the back-connections intended for securing the bracket to which one of the fore-and-aft braces to the front-head is attached. For drilling the flange of the back-head a bracket is used to carry the arm B in place of the shaft A used for the front-head. The holes intended for socket-bolts are utilized for securing this bracket.

"A template of iron $\frac{1}{2}''$ thick is used in the furnaces for guiding the drill and to avoid the loss of time that would be occasioned by the necessity of stopping to '*draw*' the holes if a template were not used. This template is laid out to the proper pitch of rivets, and the holes carefully punched $\frac{3}{16}''$ smaller than the finished size of hole. It is then put in position and the drill run through it and the furnace-sheet, reaming the holes out to the proper size as it goes through. After drilling one furnace the holes in the template are the proper size for the next. This device is found to answer admirably, as the twist-drills used follow the punched holes and ream them out equally on all sides.

"To avoid the expense of making templates for drilling the shells the following method is being adopted for the two new boilers now building here: The outside longitudinal straps and the circumferential edges of the shell-sheets are carefully laid out and the rivet-holes punched $\frac{3}{16}''$ smaller than the finished size before bending. The sheets are then bent and fitted together in sections, with the outside and inside longitudinal straps held in place by tack-bolts. Each section is then put on a rough turntable mounted on a car-truck in the machine-shop, and drilled by means of a patent drill capable of being moved up and down on an upright shaft erected for the purpose, while each longitudinal seam is brought to the drill by turning the shell round on the turn-table. The punched holes in the outside straps serve as templates to guide the drill through the shell-sheet and inside strap. This machine averaged about 240 holes in a day of ten hours.

"The two sections are then set up on end, one on top of the other, and the circumferential butt-strap carefully fitted and securely tacked. The longitudinal seams of the two sections are riveted up, the shell placed horizontally on rollers, the back-head fitted in, and the circumferential strap is then drilled by the machine represented by figure 2, the $\frac{3}{4}''$ holes previously punched in the edges of the shell-sheets acting as templates to guide the drill, which reams them out to their full size, $1\frac{1}{8}''$, and then drills through the solid plate. The rivet-holes for the heads, having been previously punched in the shell-sheet, are used as templates for drilling the flanges of the heads, using the machine represented in figure 1 and previously described. This machine has drilled

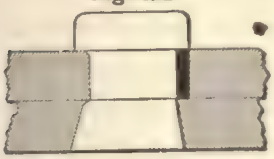
two rows of holes around the entire head (from 180 to 200) in eight hours, including the time expended in moving the shell around to get at the holes at the bottom of the boiler. After the furnaces have been secured in place the front-head is fitted and drilled in the same manner."

One man and two apprentices are required to run these machines. The man attends to the feed of the drill, one apprentice directs the nozzle of the hose, and the other apprentice stops and starts the engine, which is provided with a brake.

It is necessary to be careful, especially in drilling deep holes, to let the jet of the lubricant strike the end of the drill constantly.

7. Riveting.—The holes having been drilled or punched, the sheets are fixed in position and temporarily secured by bolts and nuts. When the holes have not been accurately spaced, so as to be "*half-blind*," or not perfectly coincident in the joint, it is a common practice to resort to "*drifting*"—*i.e.*, to drive through both a tapered steel pin or drift, thus drawing the sheets up and enlarging the holes by main force. This practice produces highly injurious strains on the sheets; it causes the edges of the holes to bulge and gives to the holes irregular shapes, difficult to fill with the rivet (see figure 32). Sometimes, when the want of coincidence is slight, a smaller rivet is inserted. Both practices are to be condemned; such imperfect holes should be reamed or drilled out, and a larger rivet should be used which will fill and cover the enlarged hole completely.

Fig. 32.



The operation of riveting by hand requires the services of two "*riveters*" and one "*helper*" in the gang, besides the boy who heats the rivets in a forge. The shank of the rivet is brought to a white heat, but the head is not made quite so hot; care has to be taken not to burn the rivet. The boy passes the rivet to the helper, who places it in the hole, drives the head close up to the plate, and holds a heavy hammer or other mass of iron firmly against the head of the rivet while the riveters beat the protruding end of the shank into the required shape. First, however, they strike a few blows around the rivet-hole on the plate to bring the sheets into close contact. The first blows on the rivet must fall squarely on the point, so that the rivet is upset throughout its whole length and fills the hole completely before a shoulder is formed. According to the form to be given to the point, the rivet is either beaten down roughly to shape and then finished by a "*set*," or cup-shaped die, held by one riveter and struck with a heavy hammer by the other; or it is beaten to a conical shape with light hammers. The hammers used by riveters vary from 2 to 7 lbs. in weight, according to the character of the work and the size of the rivets; and the holding-up hammers weigh from 10 to 40 lbs.

To drive each $\frac{5}{8}$-inch rivet an average of 250 blows of the hammer is needed. The largest rivets that can be worked by hand are $1\frac{1}{4}$ inches in diameter. For the operation of riveting expert and skilful workmen are required, that the rivets may be fixed sound and firm and that all unnecessary hammering may be avoided. The conical points of the rivets become brittle and are liable to crack or drop off altogether when the hammering is continued after they have grown cold.

Daniel Adamson, in a paper read before the Iron and Steel Institute in 1878, states as his experience that "nearly all ordinary bar or boiler irons and mild steels will endure considerable percussive force when cold and up to 450° Fahr., after which, as the heat is increased, probably to near 700°, they are all more or less treacherous and liable to break up suddenly by percussive action."

The specimens experimented upon stood the bending test perfectly when cold and at a red heat.

Modern direct-acting, steam or hydraulic riveting-machines have a cup-shaped die on the end of the piston-rod, which presses against a fixed die. The work is brought into position for riveting by cranes; the rivets are placed in the holes by hand, the pressure is admitted to the cylinder, and the die on the piston-rod is pressed forward upon the hot rivet and squeezes it into shape.

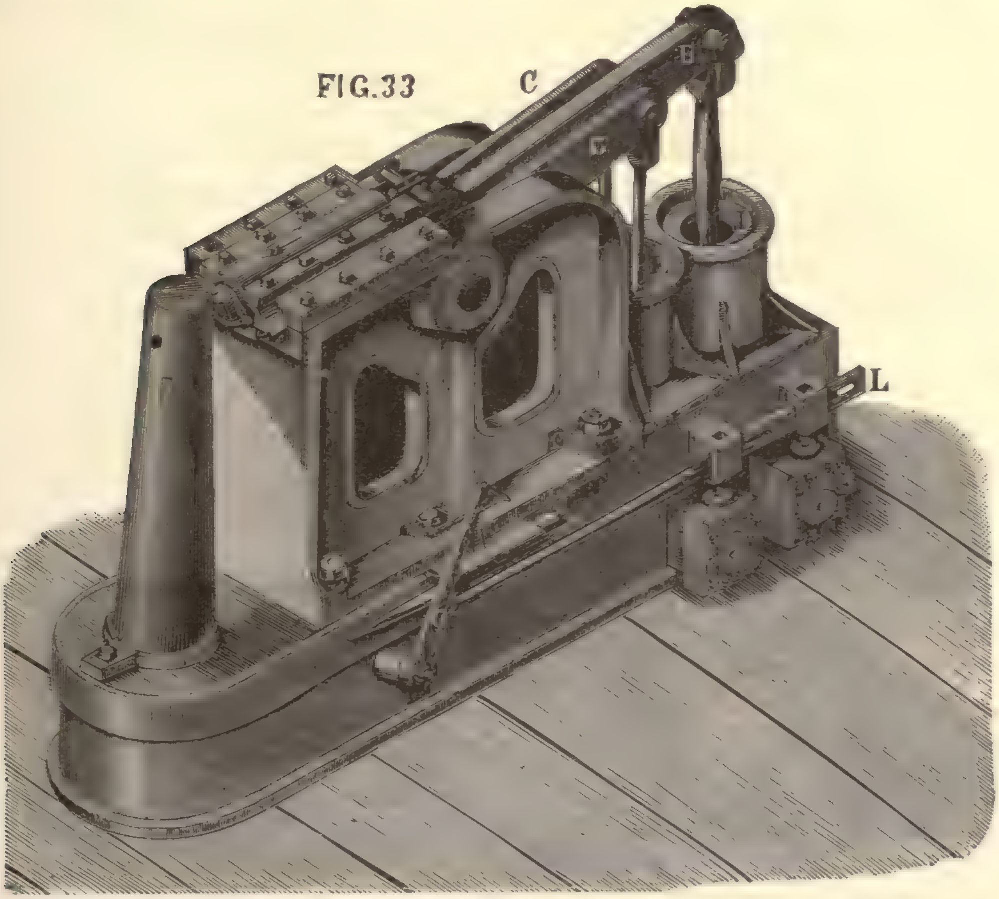
The riveting-machine accomplishes this work with great rapidity and regularity, without the disagreeable noise of hand-riveting; the sheets are pressed close together during the operation, and the rivets are acted upon while at the proper temperature; the steady pressure compresses them evenly throughout their length, till the plastic metal flows into every irregularity of the rivet-hole, and the surplus metal may be formed into heads of any size and form.

It is found that rivets driven by hand fill up the hole very well immediately under the points formed by the hammer, but that the same effect is not produced at every point in the length of the rivet, especially when the holes are irregular. So great is this difficulty that in hand-riveting shorter rivets must be used, because it is impossible to work effectively so large a mass with a hammer as with a machine. The heads of the machine-rivets are, therefore, larger and stronger, and will hold the plates together more firmly than the smaller hand-riveted heads. There are, however, many parts of a boiler that are inaccessible to the machine and must always be riveted by hand.

Figure 33 represents the steam-riveting machine built by the *Providence Steam-engine Company*, *Providence*, *R. I.* It has an annular die, A, surrounding the cupped die which acts on the rivet, both dies having an independent horizontal motion. The middle lever, B, acts on the cupped die, and the two levers C C act on the annu-

lar die. The long arm of each lever is connected by means of a forked rod to the piston of the single-acting steam-cylinders, D and E. When the work has been moved into position between the standard F, carrying a stationary cupped die which bears against

FIG.33



the head of the rivet, and the movable dies, the slotted sliding-bar L is moved by means of the handle H. This sliding-bar operates the steam-valve of each cylinder, regulating the admission and exhaust of the steam, and is adjusted in such a manner as to admit steam to the cylinder E first, so that the annular die strikes a blow around the rivet-hole, forcing the plates into close contact, and while it is held in that position a further motion of the handle H admits steam to the cylinder D which works the cupped die. The latter is made to deliver one or two powerful blows on the point of the rivet.

In *Tweddell's hydraulic machine-tools* the power is furnished by an hydraulic ac-

cumulator, consisting of a cast-iron cylinder in which a plunger moves which carries the weight producing the pressure on the water pumped into the cylinder. For punching and shearing machines Tweddell uses a water-pressure equal to about fifty atmospheres.

His riveting-machines are worked by special accumulators capable of exerting a pressure of about 100 atmospheres. They consist of a vertical cylinder, loaded with weights, which moves along a plunger fixed at the lower end and having a channel through the centre which establishes communication between the pumps and the annular space between the cylinder and the plunger. The volume of water contained in the accumulator is small, and consequently the fall of the cylinder during the operation of the machine is relatively great; the vis viva of the falling counter-weights being designed to increase the effect of the water-pressure as the ram of the riveting-machine is arrested.

The use of hydraulic power has special advantages for riveting-machines: violent shocks are avoided, and the pressure on the ram may be varied at will for different kinds of work by changing the weights on the accumulator. Each rivet, whether long or short, is driven with a single progressive movement, controlled at will by the operator.

These riveting-machines are made either stationary or portable. In stationary machines the hydraulic cylinder, made of bronze, is firmly attached, in a horizontal position, on the top of a heavy cast-iron frame; the die fixed to the end of the ram is made of wrought-iron.

In the portable riveters the hydraulic ram acts on a lever, the arms of which have the proportions of two to one; the die is fixed to the short end of the lever, the fulcrum being at the long end, but provision being sometimes made to interchange the position of the die and the fulcrum. A fixed die is attached in a corresponding position to the casting of the hydraulic cylinder. In the different sizes of these portable hydraulic riveters manufactured by Wm. Sellers & Co., Philadelphia, the levers are made 6 inches and 12 inches long, 9 inches and 18 inches long, and 12 inches and 24 inches long respectively. The portable riveter rests in a frame having the form of a quadrantal arc, by which it is suspended from a hoisting-machine on an overhead-carriage travelling on rails. By this means the riveting-machine can be placed in any position required for the work to be done, and moved over a large area; the work rests on trestles and the riveting-machine is moved along or around it. The water is carried from the accumulator to the riveting-machine through jointed or flexible pipes.

The operation of the machine is described by the manufacturers as follows:

"One man raises and lowers the riveter, adjusts it to the rivets, and then closes the

dies on the rivets. Boys drop the red-hot rivets into place, with the head of the rivet uppermost in horizontal work. With a skilful operator as many as 6 to 10 red-hot rivets may be put in place ahead of him, and he can, on beam-work, drive from 10 to 16 rivets per minute.

"In using the hydraulic riveting-machine to advantage the rivets should be heated rapidly and uniformly."

The weight of a portable riveter capable of driving rivets $\frac{3}{4}$ inch in diameter is about 450 lbs.

The number of rivets put in for a day's work depends upon the diameter of the rivets, their position with regard to greater or less accessibility, the description of the points, and the care taken during the operation. Reed furnishes the following table as representing the practice of hand-riveting at a large English private shipyard (a day's work is taken at ten hours):

Position of rivets.	Diameter of rivets and description of points.	Number of rivets put in by a set of riveters for a day's work.
In outside plating......	1-inch, countersunk.......... ...	85 to 90
In bulkheads, etc..... ..	$\frac{3}{4}$-inch, snap....................	180
In made beams, etc.....	$\frac{5}{8}$-inch, snap....................	200
In beam ends..........	1-inch to $1\frac{3}{16}$-inch, hammered....	50
In deck-plating........	$\frac{7}{8}$-inch, countersunk............	140

Fairbairn states that, with two men and two boys attending to the plates and rivets, his machine could fix 8 rivets of $\frac{3}{4}''$ diameter per minute, while three men and one boy, by hand-riveting, could only fix 40 rivets per hour; hence the quantity of work done in the two cases was as 12 to 1, and one man's labor was saved.

Grantham states that with Garforth's riveting-machine 6 rivets can be put in per minute, while 20 rivets per hour is the work of a set of riveters.

At Pittsburgh, Louisville, and other places west of the Alleghanies rivets are driven cold in boiler-work. It is evident that none but the very best material can be used for such rivets, and this is claimed as an advantage for this process; besides, these rivets are free from the danger of being burnt, and cannot become loose in the hole by contracting diametrically in cooling after being hammered down. The extensive use of cold-hammered rivets in the high-pressure boilers of the Western river-steamers proves conclusively that tight joints can be made with cold rivets. When the total thickness

of the plates is more than 4 inches it is better not to employ hot-riveting, because the contraction in cooling might spring up or shear off the head of the rivet; instead of using cold rivets of such great length it is often better to use turned screw-bolts of very slight taper.

In using steel rivets care must be taken to heat them uniformly, not above a cherry-red heat, and to work them down and finish them off as quickly as possible. Reed says on this point: "When the [steel] rivet has not been sufficiently heated, or the riveters have not been expert, they have had great trouble in cutting off the burr, and in doing so have often broken away part of the countersunk point with the burr. On the other hand, if the rivets are heated much above a cherry-red heat they cannot be properly knocked down, as they waste away under the blows of the hammer. If great care is not taken the rivet may be overheated to an extent not sufficient to prevent its being knocked down, but sufficient to greatly deteriorate the quality of the finished rivet. It is advantageous to have plain knock-down or conical points to steel rivets in preference to snap-points, as a burnt or overheated rivet is then more easily detected by the crack round the edges."

8. Forms of Rivets.—Rivet heads and points are of various shapes. Figure 34 shows the dimensions of a $\frac{3}{4}$-inch rivet of the form most commonly used in boiler-making. In hand-riveted boilers the rivet-points are generally made conical (figure 35).

Fig. 34.

Fig. 35.

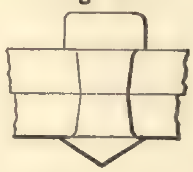


Fig. 36.

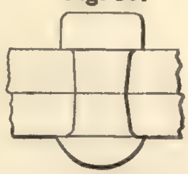
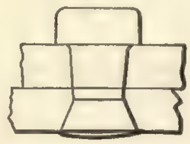


Fig. 37.



The riveting-machine and the hand-set make hemispherical heads and points, also called snap-points (figure 36). In places where it is essential to preserve a smooth surface the rivets are countersunk (figure 37).

The lengths of shank required to form these different rivet-points are given in the following table:

TABLE XXV.

Kind of point.	Length of shank required.
Countersunk point for 2 thicknesses of sheets......	1 diameter.
" " for 3 thicknesses of sheets......	1 diam. + $\frac{1}{8}$ inch.
Snap-points..........................	$1\frac{1}{4}$ diam.
Conical points..........................	$1\frac{1}{4}$ to $1\frac{1}{2}$ diam.

Snap-points present generally a greater area of metal to resist shearing than conical points; they are also considered stronger, because in forming them by means of a die the metal is compressed, while in the hand-hammered conical point the metal is spread. Snap-points cannot well be formed on hand-hammered rivets over $\frac{3}{4}$ inch diameter, because too heavy a hammer would be required. Snap-points are extensively used for interior work in shipbuilding.

Conical points are considered to make a tighter joint, since they cover a larger surface. The height of the cone should be about three-quarters of the diameter of the rivet; if made too flat they are weak and waste away rapidly through corrosion.

The enlarged hole necessary for *countersunk* rivets weakens the plate, while the rivet is correspondingly stronger. They are used necessarily for the outer plating of vessels. In boiler-making they are only used on the strengthening-rings of manholes and other openings, on furnace-fronts, and where it is necessary to clear a flange, etc. Countersunk rivets should be avoided where the stress on them consists in a pull in the direction of their length.

Sexton recommends to use a uniform angle of 60° for the countersinking tool for holes of all sizes, and not to countersink the hole down to a thin edge, but to leave a portion of it cylindrical, say about one-fourth of the thickness of the sheet (figure 38). Other writers recommend to use such an angle that the apex of the cone falls on the line where the shank joins the head of the rivet.

Fig. 38.

9. Styles of Joint.—Riveted joints are either lap-joints or butt-joints. In the former case the edges of the plates lap one over the other a certain width called the lap, and the rivets are put through both sheets. In the other case the edges butt against each other and are covered by one or two narrow strips of plate called welts or butt-straps, which are riveted to each plate. The rivets are placed either all in one line at

an equal distance from the edge, or in several rows; and in the latter case they are put either directly behind each other (*chain-riveting*) or *staggered*—*i.e.*, in zigzag lines.

The following are the principal styles of joint used in boiler-making:

Figure 39 represents a single-riveted lap-joint.

Figure 40 represents a double-riveted lap-joint.

Figure 41 represents a single-riveted butt-joint with single butt-strap.

Figure 42 represents a single-riveted butt-joint with double butt-strap.

Figure 43 represents a double-riveted butt-joint with double butt-strap.

Figure 44 represents a chain-riveted butt-joint with double butt-strap.

Fig. 39.

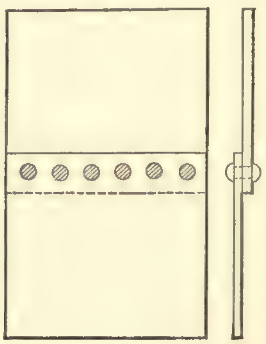


Fig. 40.

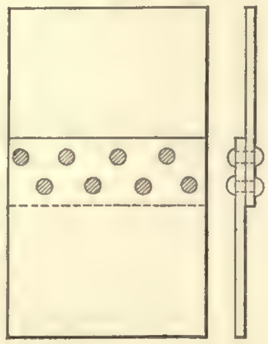


Fig. 41.

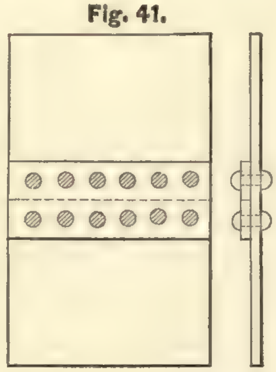


Fig. 42.

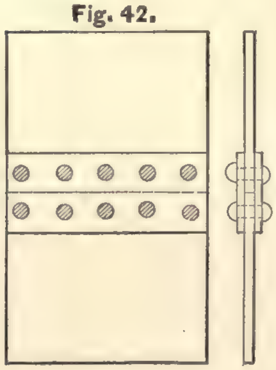


Fig. 43.

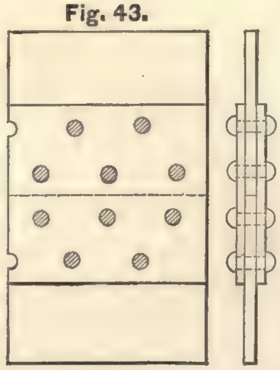
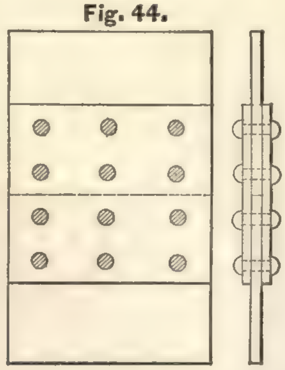


Fig. 44.

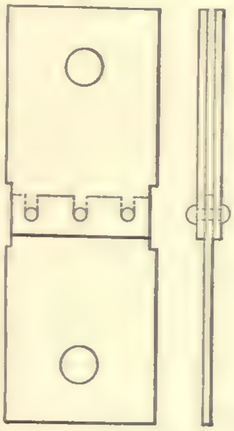


In bridge-building and ship-building a greater number of rows of rivets are often advantageously employed. In boiler-making the objects to be kept in view in selecting a special kind of joint and proportioning it are strength, economy of material and labor, and tightness.

10. Friction in Riveted Joints.—E. Clark and Reed have made experiments to determine the amount of friction in riveted joints due to the force exerted on the sheets

by the contraction of the rivets in cooling. Reed describes his experiments in the following manner: "Three plates were united by what is known as a *chain-joint*—that is, the ends of the two outer plates overlapped the end of the middle plate. The connection of the plates was made by three rivets passing through the lap, the rivet-holes in the outer plates being filled by the rivets, but the bearing-surface of the holes in the middle plate being slotted out as shown in figure 45. It will thus be obvious that when a tensile strain was brought upon the middle plate the amount of the friction could be measured by the force just able to produce a sliding motion. The breadth of the lap was three diameters, the rivets were a diameter clear of the edge of the plates, and their pitch was four diameters."

Fig. 45.

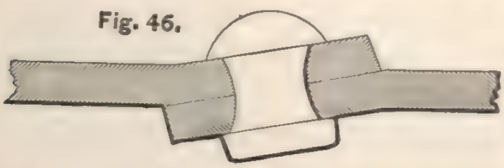


Both iron and steel plates were experimented on with different kinds of rivets; the dimensions of the plates were $\frac{1}{2}'' \times 8\frac{1}{4}''$, the rivets being $\frac{3}{4}''$; and $\frac{7}{8}'' \times 11''$, the rivets being 1 inch. The mean weight required to cause the plates to slide was 4.95 tons per rivet. Reed sums up the result of his experiments in the following words: "It thus appears that rivets with pan-heads and conical points have the advantage over both the other descriptions of riveting." . . . "It also becomes evident that countersunk riveting causes much less friction than the other systems. On comparison it will be seen that in nearly all cases steel plates and rivets give less friction than iron." . . . "The use of larger rivets with the same pitch, etc., gives an increase in the friction, but no law of increase appears to be conformed to."

The results of Clark's experiments did not differ much from Reed's.

In commenting on these results Wilson remarks: "It must not, however, be concluded that the value of a rivet is to be determined by adding to its shearing strength the amount of friction between the plates produced by its contraction in cooling. Although these two elements of strength act together in a well-filled hole, they cannot be considered as acting independently." . . . "The manner in which a severe tensile strain affects a lap-joint by pulling it athwart the line of strain (see figure 46) must also tend to diminish the friction of the plates. Long before the ultimate resistance of the joint is reached, especially with single-riveting, the friction of the plates must be greatly diminished, and cannot be regarded as materially influencing the ultimate strength of the joint. In old boilers it is probable that the tension of the rivet becomes gradually eased by the continual straining and alteration of temperature,

Fig. 46.



which will in time affect the nature of the iron." . . . "There can be no doubt that severe calking, as commonly practised, must tend to diminish the friction between the plates, especially when they are thin."

11. Straining Action on Riveted Joints.—"A riveted joint is in a certain sense an imperfect part of a structure. It cannot be so designed as to be throughout uniformly strained. It has always certain surfaces markedly weaker than the rest, at which consequently deterioration of the material or fracture by the action of the load is liable to occur. These surfaces of weakness are so related that in general the increase of one involves a diminution of the other. The joint, therefore, which will carry the greatest load before fracture will be that in which the stress reaches the breaking limit for each of these surfaces simultaneously. Since the rivet-section can in general be increased only at the expense of the plate-section, in the strongest joint the rivet and plate will reach their breaking-point under the same load. It would seem, therefore, that the proportions of a riveted joint could be determined by the ordinary rules of applied mechanics without the need of experiment. That this is not so is probably mainly due to a second condition of imperfection in riveted joints. To apply the ordinary rules for the strength of materials to riveted joints it is necessary that the distribution of the stresses on the surfaces of weakness should be known. If those stresses were as uniformly distributed as in an ordinary bar tested for tension or for shearing, the problem would be simple. But, in fact, the stresses are less uniformly distributed and the law of their distribution is unknown. Consequently the average stress on the surface of fracture of a riveted joint, when broken by a load, is less than it would be if the stress were uniformly distributed, and needs to be determined by special experiments. Further, it may be different for different forms of joint. This average stress, always less than the maximum stress which causes fracture, is here termed the *apparent breaking stress*. Hence the chief object of experiments on riveted joints is to determine the apparent breaking stresses—

(1) for the different surfaces at which each joint may fracture,

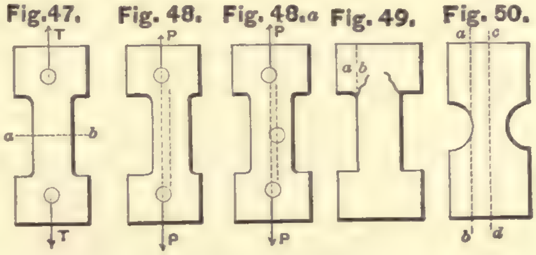
(2) for the different forms of joint.

"In certain cases allowance may have to be made for progressive deterioration of a joint, by corrosion or otherwise, which reduces the strength in certain directions more than in others. No experiments showing the amount of deterioration in such cases appear to have been made.

"Let a bar be broken at the plane $a\,b$ of area w (figure 47) by a tension, T, acting normally to the section.

"Then if the stress is uniformly distributed over the section at the moment of fracture the ratio $\frac{T}{w}$ is the real tenacity of the material. But if it is not uniformly distributed then $\frac{T}{w}$ is only the apparent tenacity, and this may be less than the real tenacity to any extent whatever. It may be useful to consider under what conditions the distribution of stress necessarily becomes unequal.

Fig. 47. Fig. 48. Fig. 48.a Fig. 49. Fig. 50.



"(1.) It will cease to be uniform if the resultant P of the load does not pass through the centre of figure of the section. Thus, in the case shown in figure 48 the stress is a varying stress, which, however, varies regularly so long as the limit of elasticity is not passed. Some of the discrepancies in the results of experiments on riveted joints are probably due to want of care in ensuring the coincidence of the line of action of the load with the centre line of the joint, in the plane parallel to the surface of the plates. Figure 48*a* shows how unequal distribution of stress may arise from this cause. In the plane at right angles to this there is probably always deviation of the load from the centre of figure. In lap-joints the load has to be transmitted from one plate through the rivet to the other plate; in butt-joints from one plate through the rivets to the cover-strip and back to the other plate. In both cases, and especially in the former case, the eccentricity of the load appears to cause a reduction of strength.

"(2.) The stress may be rendered unequal by the local action of contiguous material. Thus, a bar with square corners (figure 49) is known to break with a low apparent tenacity. The unstrained material at *a* prevents the elongation of the contiguous material at *b*, which consequently gets an excessive proportion of the load, and the fracture begins at the corners.

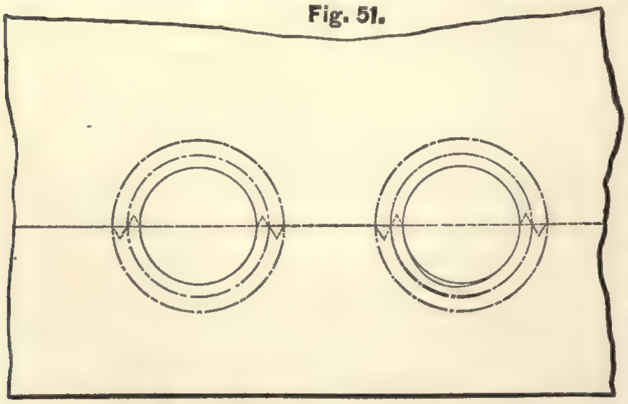
"Now, in the portion of metal between two rivet-holes a similar action probably occurs. The outside fibre *a b* (figure 50) has less freedom of elongation than the central fibre *c d*, because it is attached to the comparatively unstrained material behind the rivet. Hence, instead of breaking simultaneously over the whole section, fracture probably begins at the edges of the hole, and proceeds because the reduction of area causes increase of stress in the part remaining unbroken. This is sometimes shown by the fact that the parts of the plate will not fit after fracture. There appears to be a slight reduction of strength in plates with a hole drilled in them as compared with solid plates, and this is probably due to the cause now under consideration. It is also probable that this reduction of strength may really be greater than appears in these

experiments. Short bars are known to give a higher average tenacity than long bars. Now, a bar with a hole drilled in it is virtually a very short bar, and it ought, therefore, if there were no cause of diminution of strength, to show a higher tenacity than ordinary test-bars. But, in fact, there is generally a loss of strength.

"In some experiments there is a curious apparent increase of strength after drilling. Thus, in one of Mr. Stoney's experiments the drilled plate was $7\frac{1}{2}$ per cent. stronger than the undrilled plate. In some experiments by Mr. Parker the plain plate carried 26.4 tons, while a plate punched and annealed carried 31.7 tons. See also the table of treble-riveted joints given further on. (*Section* 15 *of the present chapter*.) Mr. Adamson also finds that the tenacity through a line of drilled holes is a little greater than the tenacity of the plate before drilling. Discrepancies of this kind may be due to the holes causing fracture at a section stronger per square inch than other parts of the plate. An ordinary test-bar breaks at the weakest part of a more or less considerable length of bar.

"(3.) If the material in the neighborhood of the surface of fracture is initially (before the application of the load) in an irregularly-strained condition, or has in different parts unequal power of elongating, then the stress will not be uniform at the moment of fracture, and the apparent tenacity will be less than the real tenacity. This is the cause of the loss of strength due to punching. By the action of the punch metal is caused to flow laterally into the surrounding metal. This induces initial stresses in an annulus of metal round the hole, and very probably also, as M. Barba thinks, alters its power of elongation. If the power of elongating is diminished in part of the metal, that part gets an excessive proportion of the load and breaks before the rest is fully strained. The result of either loss of tenacity or loss of ductility is to diminish the apparent tenacity of the metal to an extent which certainly reaches in some cases 20 to 30 per cent. Figure 51 shows a possible condition of the bar after punching, the ordinates of the dotted curves representing the stresses. Immediately round the hole is an annulus in which the stress is compressive, the compression being due to material forced in. To balance the forces in this ring an annulus in which the stress is tension must surround it.

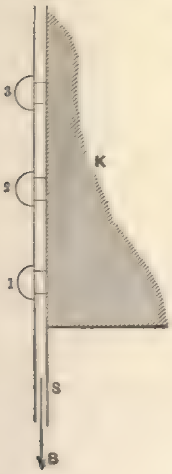
Fig. 51.



"In some experiments there appears to occur a serious diminution of the apparent tenacity in riveted joints when the bearing-surface of the rivets on the plates is too small, and when consequently the crushing pressure between the rivet and plate is excessive. It is possible that this is due to an action like that which occurs in punching. The pressure of the rivet may cause a lateral flow of the metal, and alter either the stress or the elasticity of a ring of metal round it. The stress on the tearing section being then unequal, a low apparent tenacity is found." (*First Report of the Committee of the Institution of Mechanical Engineers on the Form of Riveted Joints.*)

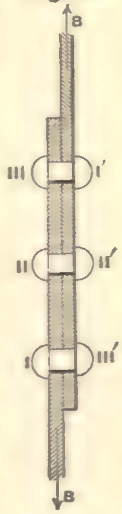
In multiple-riveted joints of materials of different elasticities—*e.g.*, steel and iron, or cast and wrought iron—the outermost row of rivets has to bear the greater stress. If

Fig. 52.



the elastic rod S (figure 52) is riveted to a non-elastic body, K, by several rows of rivets, the row 1 must bear the entire stress B, for the part of B assigned to 2 must act by tension on 1 2, tending to stretch it. Since 1 does not yield, on account of the deficient elasticity of K, the part of B assigned 2 is transferred back to 1 by compression.

Fig. 53.



If two bodies, whose elongations for the same stress are nearly equal, are riveted double or triple they strive to attain unequal elongations between rivets, because the forces acting on the adjacent parts are not equal. Denote the total tension on the joint by B, the stresses on the rivets (figure 53) by I, II, III, and I′, II′, III′, and the stresses on the intermediate portions of the plates by I II, II III, and I′ II′, II′ III′, then

$$\mathrm{I} = \mathrm{I}'$$
$$\mathrm{I\ II} = \mathrm{I'\ II'} = \mathrm{B} - \mathrm{I}$$
$$\mathrm{II} = \mathrm{II}' \text{ and } \mathrm{III} = \mathrm{III}'$$
$$\mathrm{II\ III} = \mathrm{II'\ III'} = \mathrm{B} - \mathrm{I} - \mathrm{II}$$

The parts I II and II′ III′ are therefore under the action of forces of different magnitudes—viz., B − I and B − I − II. The rivet I cannot yield to the elongation of I II, and a portion of this force must act as pressure on I. The same holds true of the portions II III, I′ II′, and the rivet I′.

Hence the weak point of every riveting which is more than double lies near the outermost rivet in the direction of the strain. (*Weyrauch*, '*Strength of Iron and Steel Construction.*')

12. Strength of Materials in Riveted Joints.—The *tensile strength* of boiler-

plates at the joints per square inch of section is generally less than that of the original plates; but this loss of tenacity varies according to the treatment received by the plates in the process of construction. When the rivet-holes are drilled the strength of the material is not diminished to an appreciable extent. When the holes are punched the loss of tenacity varies with the form of punch used and with the quality of the material; it is greater for hard than for very ductile materials, and is generally greater for steel than for iron; it increases with the thickness of the plates, and as the diameters of the punch and of the die-hole are more nearly alike. Experiments on punched iron plates show a loss of tenacity varying from 5 to 20 per cent. of the original strength of the plates. In steel plates punching produces a loss of tenacity varying from 8 to 35 per cent. of the original strength; but the plates can be restored to their original tenacity by annealing them after punching, or by reaming out the punched holes. (*See section* 5 *of the present chapter.*)

In an experiment made by Adamson the strength of a perforated bar was increased 5.8 per cent. by driving a turned pin into the hole, so as to prevent the metal round the hole from collapsing into an elliptical shape; thus producing more nearly the same condition as obtains in riveted joints.

It is generally assumed that the *shearing strength* of wrought-iron is 80 per cent. of its tensile strength, if the shear is in a plane perpendicular to the direction of rolling, and if the tension is applied parallel to the direction of rolling. In a paper on the strength and proportions of riveted joints, by W. R. Browne, communicated to the Institution of Mechanical Engineers in 1872, it is assumed that the shearing resistance of iron rivets

in single-shear is	22 tons per square inch.
in double-shear is........................	21 " "

Some of Fairbairn's experiments on the shearing resistance of rivets gave the following results:

Rivet-holes drilled, edges of holes sharp..........	19.23 tons per square inch.
Rivet-holes drilled, edges of holes rounded........	21.52 " "
Rivet-holes punched............................	20.95 " "

Experiments made by David Greig and Max Eyth on Taylor's Yorkshire rivet-iron and Brown & Co.'s mild rivet-steel gave for the tensile strength of the iron 22.2 tons per square inch, and of the steel 28.8 tons per square inch. The shearing resistance of the iron was 19 tons, and that of the steel 22.1 tons. Some plates riveted together were then tested, and a somewhat higher shearing resistance was found than for bars not formed into rivets. This is ascribed partly to the rivet being increased in diameter to

fill a hole larger than its normal size, partly to the friction of the plates. The hardening of the rivet is a possible cause of increased resistance of rivets as compared with simple bars.

The *crushing pressure* of the rivet on the plate is discussed by Professor W. C. Unwin in the 'First Report of the Committee of the Institution of Mechanical Engineers on the Form of Riveted Joints,' as follows:

"If F is the tension on a joint corresponding to one rivet,

d the diameter of the rivet, and

t the thickness of the plate,

then $$C = \frac{F}{d\,t} \quad \text{[I.]}$$

may be defined as the mean crushing pressure of the rivet on the plate.

"Putting S for the shearing resistance of the rivet, then, the rivets being in single shear,

$$C\,d\,t = S\,\frac{\pi}{4}\,d^2 = F$$

$$\frac{C}{S} = .785\,\frac{d}{t}, \quad \text{[II.]}$$

or the crushing pressure is greater as the ratio of the rivet diameter to the thickness of plates is greater.

"This is sometimes given as the reason why the rivet diameter should not exceed $2\frac{1}{2}$ to 3 times the plate thickness. It is by some writers asserted that if in any case C is more than 30 or 40 tons per square inch for iron joints, then the joint gives way with a very low apparent tenacity. During the application of the load the rivet-hole becomes oval, the metal of the plate is crushed and its tenacity diminished. The precise way in which the crushing affects the tenacity has not hitherto been indicated; but it is suggested above (*see section* 11 *of the present chapter*) that it produces an unequal distribution of the stress similar to that induced by punching. There are no direct experiments on the crushing of iron and steel which are of any value in determining the proper limits of crushing pressure for riveted joints. . . .

"From the very irregular distribution of the pressure on the surface of the rivet it is probable that the maximum pressure of the rivet on the plate is much greater than its mean value C."

A mathematical investigation of the stresses indicates that the maximum crushing pressure is 1.27 times the mean crushing pressure, but the writer is of the opinion that in practice the value of the maximum crushing pressure is much greater, especially with rivets in single shear.

Discussing some results obtained with actual joints which have a bearing on this question, he finds that there seems to be a tolerably regular increase of apparent tenacity as the crushing pressure diminishes, and that the diminution of tenacity is sensible in lap-joints where the crushing pressure exceeds 30 tons, and was very great in some cases where the crushing pressure reached 40 tons. These remarks apply, however, only to iron lap-joints. Experiments with butt-joints show great anomalies.

"With steel joints also, even with very high crushing pressures, no regular effect on the tenacity is traceable. It seems possible to the reporter that the explanation of these anomalies may be found in the variation of the relative hardness of the rivets and plate. If the rivet is sensibly harder than the plate, the plate will suffer; but if the rivet is sensibly softer than the plate, the rivet will suffer. With iron plates sometimes the rivet and sometimes the plate is the harder. With steel the rivet appears to be generally softer than the plate. It must be borne in mind that this suggestion is only offered as a conjectural explanation of anomalies which, unless they are due to errors in the experiments, are extremely puzzling."

13. Proportioning Riveted Joints.—A riveted joint subjected to tension can break—

(1) By the tearing of the plate; in this case its strength is measured by the tensile strength of the plate multiplied by its least sectional area, which obtains on a line passing through the rivet-holes, and depends upon the thickness of the plate and the diameter and spacing of the rivets;

(2) By the shearing of the rivets; in this case its strength is measured by the shearing strength multiplied by the sectional area of the rivets;

(3) In consequence of the thrust exerted by the rivets on the plate, which may cause it either to be crushed (figure 54), or to split (figure 55), or to have a portion sheared

Fig. 54.

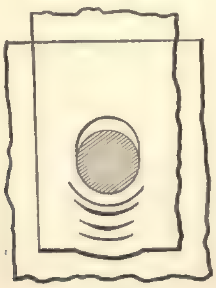


Fig. 55.

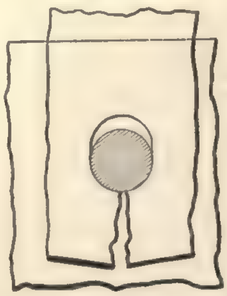
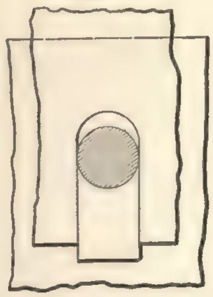


Fig. 56.



out (figure 56) from the rivet-holes to the edge of the plate; and in this case the strength of the joint depends on the diameter of the rivets, the thickness of the plate,

the width of the lap, and a coefficient of resistance depending on the nature of the fracture. The shearing of the plate from the rivet-holes to the edge is, however, not likely to take place with the ordinary proportions of lap and rivets.

The thickness of the plates, the diameter and spacing of the rivets, and the width of the lap must be proportioned in such a manner that the strength of the joint approaches as nearly as possible the strength of the whole plate, and that the same liability exists for the different kinds of fracture to take place; at the same time the tightness of the joint and facilities of construction have to be taken into consideration.

Assuming that the average shearing strength of iron rivets is 19 tons per square inch, and that the crushing pressure of the rivets on the plates should not exceed 30 tons per square inch (*see sections* 11 *and* 12 *of the present chapter*), we can find the proper diameter of a rivet for a given thickness of plates by introducing these values into *formula* [*II.*] *of section* 12 *of the present chapter*, viz.:

$$\frac{C}{S} = \frac{30}{19} = 0.785 \frac{d}{t}$$

consequently $$d = 2\,t,$$

for joints in which the rivets are in *single-shear.*

When the rivets are in *double-shear* they will bear about 90 per cent. more than the same rivets in single-shear, and under these conditions equation [II.] assumes the following form, viz.:

$$C\,d\,t = 1.90\,S\,\frac{\pi}{4}\,d^2;$$

hence $$\frac{C}{S} = \frac{30}{19} = 1.50\,\frac{d}{t},$$

consequently $$d = 1.05\,t.$$

In practice, when the rivets are in single-shear, d is generally made equal to $2\,t$ for plates up to $\frac{3}{8}$ inch thick. But this proportion is gradually decreased for thicker plates, because the formula $d = 2\,t$ would give rivets of so large a diameter that they could not be spaced close enough to make a steam-tight joint and at the same time make the plates and rivets of equal strength; and, when the thickness of the plates exceeds $\frac{9}{16}$ inch, the rivets would become so large that they could not be properly worked down. In boiler-making rivets exceeding $1\frac{1}{4}$ inches in diameter are rarely used.

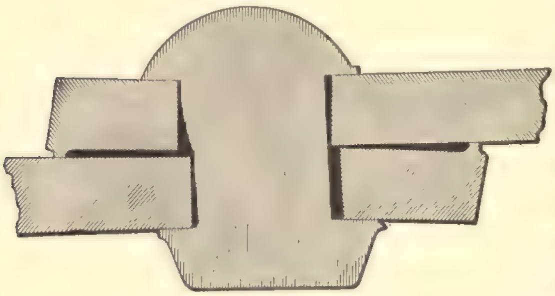
When the plates to be connected are of unequal thickness the diameter of the rivets is proportioned to the thicker plate. When more than two plates are to be connected the diameter of the rivets is increased by about one-eighth inch.

For steel boiler-plates it is better to use steel rivets than iron rivets, which should

be of somewhat smaller diameter in proportion to the thickness of the plates, and spaced correspondingly closer, than iron rivets with iron boiler-plates.

The diameter of the rivets being determined by the thickness of the plates, it is convenient to express the pitch of the rivets and the width of the lap in terms of the diameter of the rivets.

Fig. 57.



The width of the lap, measured from the centre of the rivet-hole to the edge of the plate, has been fixed practically at 1.5 d. This gives ample strength to resist the thrust of the rivet, and makes a proper allowance for calking; too large a lap does not make a tight joint, since the sheets are apt to be forced apart by severe calking (figure 57).

14. Lap-joints.—*The single-riveted lap-joint* requires less labor and material than any other riveted joint; but its strength, compared with that of the solid plate, is small, because the sectional area of the plate in the line of rivets is greatly reduced, and on account of the unequal distribution of the stresses. In boilers this joint is used especially in the furnaces and back-connections, where it is advantageous to make the lap as narrow as possible, and in those parts which are not subjected to steam-pressure, and where great strength and tightness are not required, as for chimneys, uptakes, connections, etc.

Calling the total tensile force applied to a single-riveted joint.......... F,
the ultimate tensile strength of the plate per unit of area.......... T,
the ultimate shearing strength of the rivets per unit of area........ S;
and representing the number of rivets in the joint by.............. n,
their diameter by.. d,
the thickness of the plates by.................................. t,
the pitch of the rivets by...................................... p,
we can express the width of the joint by.......................... np.

The dimensions of the rivets and of the plate being so proportioned that they offer equal resistance to F, and supposing this stress to be borne equally by every part of the plate in proportion to its sectional area, we have the equation:

$$F = n d^2 .7854 S = n (p - d) t T;$$

and

$$p = d^2 .7854 \frac{S}{t T} + d.$$

Since, with the dimensions ordinarily used in boiler-making, the value of d varies between $2\,t$ and $1.5\,t$, the values of p lie between $d\left(1+1.5708\frac{S}{T}\right)$ and $d\left(1+1.1781\frac{S}{T}\right)$.

In using these formulæ for calculating the value of p we must insert for T and S the values of the *apparent* tensile and shearing strengths of plates and rivets in single-riveted lap-joints, as found by experiment. (*See section* 15 *of the present chapter.*) The sectional area of the plates in a boiler is reduced continually by corrosion, while the shank of the rivet remains intact. This action must be taken into account in proportioning a joint.

D. K. Clark says that "the shearing section of rivets should not in any case exceed the net section of the plate, and that the maximum strength of joint is attainable when the shearing section is from 90 to 100 per cent. of the net section of the plate." Making the area of the rivets 90 per cent. of the net section of the plate, the value of p, for $d = 2\,t$, becomes $p = 2.745\,d$; and for $d = 1.5\,t$, $p = 2.309\,d$. These values do not differ much from ordinary practice.

The double-riveted lap-joint is from 20 to 33 per cent. stronger, and is more easily kept tight, than the single-riveted joint. It is used most extensively for steam-tight joints which do not come in contact with the fire and hot gases.

Retaining the notation given above, we have the equation:

$$F = n\,d^2\,.7854\,S = \frac{n}{2}(p-d)\,t\,T;$$

and

$$p = d^2\,1.5708\,\frac{S}{t\,T} + d.$$

Making the area of the rivets 90 per cent. of the net section of the plate, the value of p, for $d = 2\,t$, becomes

$$p = 4.4907\,d;$$

and for $d = 1.5\,t$,

$$p = 3.618\,d.$$

Fig. 58.

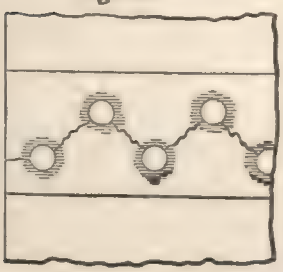
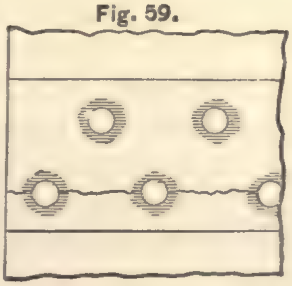


Fig. 59.



The rivets of a double-riveted joint in boilers are generally placed in a zigzag line. Some of Brunel's experiments show that when the rows of rivets are too close the line of fracture is a zigzag, running backward and forward between the rows (figures 58 and 59), and a much greater section of metal is divided than if the fracture took place on a line passing through the centre of the rivet-holes in either row. This is explained by the fact that punching weakens the sheet to some distance around the

hole, and that the amount of this weakening effect on the area represented by the zigzag line is twice as great as that on the area represented by the straight line between two contiguous holes in the same row, as has been illustrated by the shading around the holes. Brunel found that *the distance between the two rows of staggered rivets should be two-thirds of the pitch of the rivets.*

In chain-riveting it is safe to make the distance between the centre lines of the rows of rivets equal to 2½ diameters of the rivets.

Treble and quadruple riveted lap-joints are sometimes, but rarely, used for the shell of cylindrical boilers. With plates of ordinary thickness, in which the diameter of the rivets is from 1½ to 2 times the thickness of the plates, multiple-riveting makes the pitch of the rivets so large that the joint cannot well be calked steam-tight. This objection does not exist in the case of thick plates, in which the diameter of the rivets exceeds but little or nothing the thickness of the plates. The increase of strength obtained by increasing the rows of rivets is, however, not proportionate to the additional labor and material required for making the joint, on account of the very unequal distribution of the stresses. (*See section* 11 *of the present chapter.*) The dimensions of multiple joints may be calculated by formulæ similar to those given for single and double riveted lap-joints, introducing for S and T the values given in Table XXVI.

15. Experiments on the Strength of Lap-joints.—The experiments made by Fairbairn in 1838 have served up to the present time as the basis for calculating the strength of riveted joints. According to these experiments the strength of a double-riveted joint is 70 per centum of the strength of the plate, and of a single-riveted joint 56 per centum. Of these experiments it is necessary to remark:

1st. That the results are only for the case in which the rivet-holes diminish the section of the plate 30 per centum, while for the most part in practice, and particularly for the single-riveted joint, that loss is very much greater.

2d. That the experiments were made on plates of only 0.224 inch thickness.

3d. That the experiments gave 46, and not 56, per centum for the strength of the single-riveted joint; the coefficient was arbitrarily increased by Fairbairn to cover certain imperfections in the experiments.

This increase was partly made for the purpose of allowing for the increase of strength given to riveted joints by arranging contiguous plates in such a manner that their joints do not lie in the same line; but the increase of strength due to this arrangement is much greater with narrow plates, such as were formerly in general use, than with wide plates, such as are nowadays manufactured.

Experiments on various plate-joints made by W. Bertram at Woolwich Dockyard

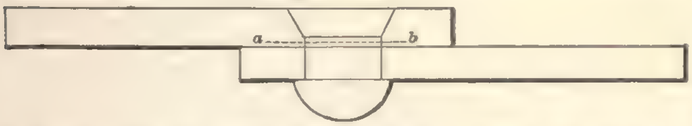
were published and discussed in 1860 by D. K. Clark. The thicknesses of the plates were $\frac{3}{8}$ inch, $\frac{7}{16}$ inch, and $\frac{1}{2}$ inch, and in the single-riveted joint the net sectional area of the plates in the line of rivets was 62.5 per cent. of the solid plate. The relative strength of the joints of the $\frac{3}{8}$-inch plate is given by him as follows:

Entire plate	100
Double-riveted joint	72
Single-riveted joint	60

He found that in the $\frac{3}{8}$-inch plate the tensile strength per square inch of net section of the single-riveted joint was nearly equal to that of the entire plate, while in the $\frac{7}{16}$-inch plate it was only four-fifths, and in the $\frac{1}{2}$-inch plate two-thirds, of the strength of the entire plate, so that the joint of the thinner plates was actually stronger than that of the thicker plates. This remarkable reduction of strength in thick plates is ascribed to the distorting leverage of the lap, which increases with the thickness of the plates. Figure 46 shows the ultimate distortion of lap-joints by the oblique action of the tension. The decrease of strength with the thickness of the plates in these experiments is, however, much greater than has been found in more recent experiments, and the strengths of the riveted joints of the $\frac{3}{8}$-inch plates, as given above, are likewise greatly in excess of the average results of experiments.

Clark found also that countersunk riveting did not impair the strength of the joint as compared with external heads, which result he explains, likewise, by the oblique stress on the lap-joint. He says: "On the principle here noticed one may account for the practically equal strength of the joints made with countersunk rivets, compared with those having external rivet-heads, notwithstanding the greater reduction of solid section by countersinking: the leverage is shortened and it may be measured from the centre of the cylindrical part of the rivet in the line $a\,b$ (figure 60), or thereabouts, toward the inner side of the plate. On the same principle the conical form of punched holes reduces the leverage and the obliquity of the pulling stress."

Fig. 60.



In the above-mentioned 'First Report of the Committee of the Institution of Mechanical Engineers' the most reliable experiments on riveted joints have been tabulated, all experiments being omitted in which the crushing pressure of the rivets on the plate was so great as probably to have affected in a considerable degree the apparent tenacity of the joint. The ratio of the tension on the joint to the area of the sec-

tion at the place of fracture is called the *apparent* tenacity of the joint, which is rendered less than the original tenacity of the iron by any injury done in drilling or punching, and by the irregularity of stress due to the crushing action between the rivets and plates, and by the irregular distribution of stress due to bending of the joint under the action of the load, etc.

From a large number of experiments on *single-riveted lap-joints* of iron plates it appears that the apparent tenacity of the plate in this joint is from 20 to 32 per cent. less than that of the original plate, with *punched* holes, and about 12 per cent. less with *drilled* holes. Since iron plates do not receive any appreciable injury in drilling, this loss in tenacity of 12 per cent. has to be ascribed mainly to the irregular distribution of the stress.

The mean *shearing* resistance of the rivets is about 6 per cent. greater in punched holes than in drilled holes. With *punched* holes the ratio of the apparent tenacity of the plates to the shearing resistance of the rivets is 85 to 100, but with *drilled* holes the plates are stronger per unit of area than the rivets in the ratio of 107 to 100.

The mean *efficiency* of the single-riveted lap-joint, in per cent. of the tenacity of the solid plate, is 44.6 per cent. when the holes are punched and 50 per cent. when the holes are drilled.

The mean results of nine experiments with *double-riveted* lap-joints of iron plates with *punched* holes give an *apparent tenacity* of the plate of 89.5 per cent., and an *efficiency* of the joint equal to 59 per cent. of the tenacity of the solid plate.

Two experiments with *drilled* iron plates and double-riveted lap-joints, by Greig and Eyth, give a mean *apparent tenacity* of 95 per cent. and a mean *efficiency* of joint of 61 per cent.

Several experiments with double-riveted lap-joints of punched iron plates 1 inch and $\frac{5}{8}$ inch thick, made by Kirkaldy for R. V. J. Knight, gave remarkably low results. The mean *apparent tenacity* of the plates at the joint was only 56.4 per cent. of the tenacity of the solid plate; and the mean of four experiments with 1-inch plates gave 34.5 per cent., and the mean of two experiments with $\frac{5}{8}$-inch plates gave 42.6 per cent., for the *efficiency* of the joint. This great reduction of strength appears to have been due to the unequal distribution of the stress in consequence of the bending of the joint under the action of the load, since two similar iron plates, 1 inch thick, with punched holes, but forming a *double-riveted butt-joint with double covering-plates*, which were tested by the same parties, gave an *apparent tenacity* of 90 per cent. of the tenacity of the solid plate.

The average values of a number of experiments with double-riveted *steel* lap-joints

make the apparent tenacity of the plates at the joint from 4 to 8.5 per cent. greater than the tenacity of the solid plate, and 21 per cent. greater than the shearing resistance of steel rivets per square inch of sectional area.

Table XXVI. contains the results of experiments with *treble and quadruple riveted lap-joints* made of steel plates with steel and iron rivets, and is compiled principally from the 'First Report of the Committee of the Institution of Mechanical Engineers on the Form of Riveted Joints.' The joints were made partly by Denny & Co., of Dumbarton, and the specimens were tested by Kirkaldy. The stresses corresponding to the actual mode of fracture of the joints are printed in heavy type; the other stresses, printed in ordinary type, are those which obtained at the moment of fracture, but are lower than those at which the joint would have given way by the respective modes of fracture. The joints marked *a*, *b*, and *c* in the table and their lines of fracture are represented in figures 61, 62, and 63 respectively. The steel plates had a

Fig. 61.

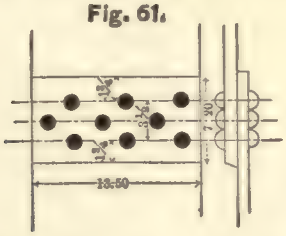


Fig. 62.

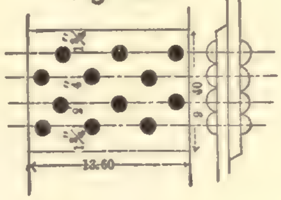
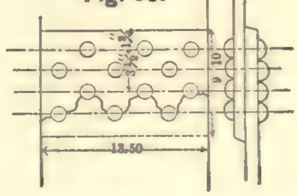


Fig. 63.



nominal thickness of $\frac{7}{8}$ inch, and the steel rivets had a diameter of 1.13 inches. The tensile strength of the rivets in these four joints was 28.9 tons per square inch, and their apparent shearing strength varied consequently from 66.5 to 71.4 per cent. of their tenacity.

TABLE XXVI.

RESULTS OF EXPERIMENTS WITH TREBLE AND QUADRUPLE-RIVETED LAP-JOINTS.—STEEL PLATES. TESTED BY KIRKALDY.

Mode of riveting.	Holes.	Tenacity of steel plate, tons per sq. inch.	Stress at moment of fracture, in tons per square inch.			Apparent tenacity of plate at joint in per cent. of tenacity of solid plate.	Efficiency of joint.	Thickness of plate.	Rivets.
			Tensile.	Shearing.	Crushing.				
Treble-riveted	Punched	31.2	**23.34**	12.0	17.58	75	52	$\frac{3}{8}$ in.	Iron.
"	"	28.8	**22.47**	12.2	16.85	78	54	$\frac{7}{16}$ "	"
"	Drilled	30.9	**36.11**	16.1	24.32	117	77	$\frac{1}{4}$ "	"
"	"	30.4	**35.00**	15.6	23.57	115	76	$\frac{1}{4}$ "	"
"	"	31.2	**35.38**	18.2	26.79	113	79	$\frac{3}{8}$ "	"
"	"	31.6	**32.75**	17.6	25.76	104	73	$\frac{1}{2}$ "	"
"	"	32.7	**31.27**	16.5	24.59	96	67	$\frac{1}{2}$ "	"
"	"	28.3	**29.88**	15.7	23.31	106	74	$\frac{1}{2}$ "	"
"	"	28.2	**30.14**	15.8	23.51	107	75	$\frac{1}{2}$ "	"
Treble-chain........	"	31.6	**35.88**	23.3	32.96	114	83	$\frac{1}{4}$ "	Steel.
"	"	29.1	**33.83**	22.0	22.10	116	77	$\frac{1}{2}$ "	"
"	"	28.6	**30.47**	22.2	21.24	107	72	$\frac{3}{4}$ "	"
"	"	27.7	**29.44**	21.5	15.83	106	69	1 "	"
Quadruple-zigzag (*c*).	Punched and reamed.	27.1	**25.34**	18.4	18.91	94	70	$\frac{7}{8}$ "	"
Treble-chain........	Drilled	31.7	32.30	**25.1**	36.01	...	79	$\frac{1}{4}$ "	Steel.
"	"	29.1	29.89	**25.5**	25.10	...	73	$\frac{1}{2}$ "	"
"	"	30.4	25.89	**23.9**	23.14	...	62	$\frac{3}{4}$ "	"
"	"	27.5	26.07	**24.1**	20.54	...	67	1 "	"
Treble-zigzag (*a*).....	Drilled and reamed..	27.4	19.74	**19.4**	19.63	...	54	$\frac{7}{8}$ "	"
Treble-zigzag (*a*)....	Punched and reamed.	27.3	21.41	**20.6**	21.25	...	59	$\frac{7}{8}$ "	"
Quadruple-zigzag (*b*).	" "	27.4	25.91	**19.2**	19.51	...	71	$\frac{7}{8}$ "	"
Treble-riveting......	Drilled	30.7	34.76	**19.1**	27.03	...	79	$\frac{1}{4}$ "	Iron.
"	"	32.2	34.95	**19.2**	27.12	...	76	$\frac{1}{4}$ "	"
"	"	28.8	31.92	**17.4**	23.93	...	77	$\frac{3}{8}$ "	"
"	"	28.8	31.84	**17.4**	23.88	...	77	$\frac{3}{8}$ "	"
"	"	27.6	26.42	**16.7**	20.80	...	67	$\frac{3}{4}$ "	"
"	"	28.0	29.22	**15.2**	20.22	...	70	$\frac{3}{4}$ "	"
"	"	30.0	25.55	**16.5**	20.10	...	60	$\frac{3}{4}$ "	"
"	"	26.7	28.16	**15.9**	20.12	...	71	$\frac{7}{8}$ "	"

TABLE XXVII.

Proportions of Single-riveted Joints.

Thickness of plate.	Fairbairn. Diameter of rivets.	* Multiplier.	Length of rivets.	* Multiplier.	Pitch of rivets.	* Multiplier.	Lap.	* Multiplier.	Wilson. Diameter of rivets.	Pitch of rivets.	Lap.
Inch.	Ins.		Ins.		Ins.		Ins.		Ins.	Ins.	
3-16	.38	..	.88	..	1.25	6	1.25	..	....	....	3 times the diameter, and never more than 3.3 times the diameter.
¼	.50	2	1.13	..	1.50	..	1.50	6	½	1¼	
5-16	.63	..	1.38	..	1.63	5	1.88	..	⅝	1⅜	
⅜	.75	..	1.63	..	1.75	..	2.	5.5	11-16	1¾	
7-16	....	..	....	4.5	.....	..	.....	..	¾	1⅞	
½	.81	..	2.25	..	2.	..	2.25	..	¾	1⅞	
9-16	....	..	....	..	....	..	....	..	⅞	2⅛	
⅝	.94	1.5	2.75	..	2.5	4	2.75	4.5	⅞	2⅛	
11-16	....	..	....	..	....	..	....	..	⅞	2⅛	
¾	1.13	..	3.25	..	3.	..	3.25	..	1	2¼	
13-16	.....	..	.....	..	.....	..	.....	..	1	2¼	
⅞	.....	..	.....	..	.....	..	.....	..	1	2¼	
15-16	.....	..	.....	..	.....	..	.....	..	1⅛	2½	
1	.....	..	....	..	.....	..	.....	..	1⅛	2½	

Thickness of plate.	Spon's Dictionary. Diameter of rivets.	Length of rivets.	Pitch of rivets.	Lap.
Inch.	Ins.	Ins.	Inches.	Ins.
3-16	⅜	⅞	1¼ to 1½	1¼
¼	½	1⅛	1½ to 1¾	1½
5-16	⅝	1⅜	1⅝ to 1⅞	1⅞
⅜	¾	1⅝	1⅞ to 2¼	2¼
7-16	..	..	....	..
½	13-16	2¼	2⅛ to 2⅜	2⅜
9-16	⅞	2½	2¼ to 2½	2½
⅝	15-16	2¾	2½ to 2¾	2¾
11-16	1	3	2¾ to 3	3
¾	1⅛	3¼	3 to 3¼	3¼
13-16	..	..	....	..
⅞	..	..	....	..
15-16	..	..	....	..
1	..	..	....	..

Thickness of plate.	Shipbuilding. Lloyd's Rule. Diameter of rivets.	Lloyd's Rule. Pitch of rivets.	Lloyd's Rule. Lap.	Liverpool Rule. Diameter of rivets.	Liverpool Rule. Pitch, etc.	H.B.M.'s D'ckyard. Diameter of rivets.	Millwall Iron-works. Diameter of rivets.	Millwall. Length with counter-sunk point.	Millwall. Length with snap-point.
Inch.	Ins.			Ins.		Inches.	Inches.	Inches.	Inches.
3-16	..	Not nearer than three nor further than four diameters apart.	Not less than 3½ diameters.	....	4 diameters apart. Heads not thicker than ⅔ of the diameter.	....	....	....	....
¼	..			....		....	½	1	1¼
5-16	⅝			½		½	⅝	1⅛	1½
⅜	⅝			⅝		⅝	⅝	1¼	1⅝
7-16	⅝			¾		¾	⅝	1⅜	1¾
½	¾			¾		¾	¾	1½	2
9-16	¾			⅞		⅞	¾	1 11-16	2 3-16
⅝	¾			⅞		⅞	⅞	1 15-16	2⅜
11-16	⅞			⅞		⅞	⅞	2 3-16	2⅝
¾	⅞			1		1	⅞	2⅜	2¾
13-16	⅞			1		1	⅞	2½	2⅞
⅞	1			1⅛		1⅛	1	2⅝	3
15-16	1			1⅛		1⅛	1	2¾	3⅛
1	1			1⅛		1⅛	1	2⅞	3¼

* Numbers by which the thickness of plate is multiplied for finding the dimensions of rivets, pitch, and lap, respectively.

TABLE XXVIIa.

FRENCH PRACTICE IN SINGLE-RIVETED JOINTS.

Thickness of plate.			From D. K. Clark's 'Manual of Rules.'								
			Diameter of rivet.			Pitch of rivets.			Lap.		
Millimetres.	Decimals of inches.	Ordinary fractions of inches.	Millimetres.	Decimals of inches.	Ordinary fractions of inches.	Millimetres.	Decimals of inches.	Ordinary fractions of inches.	Millimetres.	Decimals of inches.	Ordinary fractions of inches.
3	.118	$\frac{1}{8}$ —	8	.315	$\frac{5}{16}$ +	27	1.06	$1\frac{1}{16}$ —	30	1.18	$1\frac{5}{32}$ —
4	.158	$\frac{5}{32}$ +	10	.394	$\frac{3}{8}$ +	32	1.26	$1\frac{1}{4}$ +	34	1.34	$1\frac{11}{32}$ —
5	.197	$\frac{3}{16}$ +	12	.472	$\frac{15}{32}$ +	37	1.46	$1\frac{7}{16}$ +	40	1.58	$1\frac{9}{16}$ +
6	.236	$\frac{15}{64}$ +	14	.551	$\frac{9}{16}$ —	43	1.69	$1\frac{11}{16}$ +	44	1.73	$1\frac{3}{4}$ —
7	.276	$\frac{9}{32}$ —	16	.630	$\frac{5}{8}$ +	48	1.89	$1\frac{7}{8}$ +	50	1.97	$1\frac{31}{32}$ +
8	.315	$\frac{5}{16}$ +	17	.669	$\frac{11}{16}$ —	51	2.01	2 +	54	2.13	$2\frac{1}{8}$ +
9	.354	$\frac{11}{32}$ +	19	.748	$\frac{3}{4}$ —	54	2.13	$2\frac{1}{8}$ +	56	2.20	$2\frac{3}{16}$ +
10	.394	$\frac{3}{8}$ +	20	.787	$\frac{3}{4}$ +	56	2.20	$2\frac{3}{16}$ +	58	2.28	$2\frac{1}{4}$ +
11	.433	$\frac{7}{16}$ —	21	.827	$\frac{13}{16}$ +	57	2.24	$2\frac{1}{4}$ —	60	2.36	$2\frac{3}{8}$ —
12	.472	$\frac{15}{32}$ +	22	.866	$\frac{7}{8}$ —	58	2.28	$2\frac{1}{4}$ +	60	2.36	$2\frac{3}{8}$ —
13	.512	$\frac{1}{2}$ +	23	.906	$\frac{7}{8}$ +	60	2.36	$2\frac{3}{8}$ —	62	2.44	$2\frac{7}{16}$ +
14	.551	$\frac{9}{16}$ —	24	.945	$\frac{15}{16}$ +	62	2.44	$2\frac{7}{16}$ +	64	2.52	$2\frac{1}{2}$ +
15	.591	$\frac{19}{32}$ —	25	.984	$\frac{31}{32}$ +	63	2.48	$2\frac{1}{2}$ —	66	2.60	$2\frac{9}{16}$ +
16	.630	$\frac{5}{8}$ +	26	1.024	$1\frac{1}{32}$ —	65	2.56	$2\frac{9}{16}$ —	68	2.68	$2\frac{11}{16}$ +

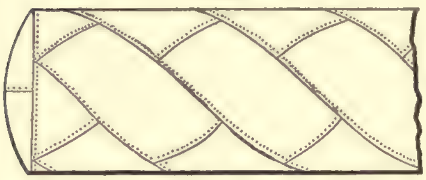
TABLE XXVIII.

PROPORTIONS OF DOUBLE-RIVETED LAP-JOINTS.

Thickness of plate.	Diameter of rivet.	Wilson.		Fairbairn.			Shipbuilding.		
							Lloyd's rule	Liverpool rule.	
		Pitch.	Lap.	Lap.	Inches.	Length.	Lap.	Lap.	Butt-strap.
Inch.		Inches.					Inches.	Inches.	Inches.
$\frac{3}{16}$	The same as for single-riveting, therefore depending upon the particular system which is selected as the standard.	..	Five times the diameter of rivet; each row $\frac{3}{8}d$ from edge.	2.084	That is, add $\frac{3}{8}$ of the depth to the single lap.	5.5 times the thickness of sheet.	Not less than $5\frac{1}{2}$ times the diameter of rivet.	..	..
$\frac{1}{4}$		$1\frac{3}{4}$		2.5				..	..
$\frac{5}{16}$		$2\frac{1}{4}$		3.134				3	$7\frac{1}{4}$
$\frac{3}{8}$		$2\frac{1}{4}$		3.333				$3\frac{3}{4}$	8
$\frac{7}{16}$		$2\frac{1}{2}$		....				$3\frac{3}{4}$	8
$\frac{1}{2}$		$2\frac{1}{2}$		3.75				$4\frac{1}{2}$	10
$\frac{9}{16}$		$2\frac{3}{4}$		....				$4\frac{1}{2}$	10
$\frac{5}{8}$		$2\frac{3}{4}$		4.584				$4\frac{7}{8}$	$10\frac{3}{4}$
$\frac{11}{16}$		$2\frac{7}{8}$		....				$5\frac{1}{4}$	$11\frac{1}{2}$
$\frac{3}{4}$		$3\frac{1}{4}$		5.416				$5\frac{1}{4}$	$11\frac{1}{2}$
$\frac{13}{16}$		$3\frac{1}{4}$		....				$5\frac{5}{8}$	$12\frac{1}{4}$
$\frac{7}{8}$		$3\frac{1}{4}$		....				6	13
$\frac{15}{16}$		$3\frac{1}{2}$		....				$6\frac{3}{8}$	$13\frac{3}{4}$
1		$3\frac{1}{2}$		....				$6\frac{3}{4}$	$14\frac{1}{2}$

16. Various Forms of Lap-joints.—On account of the inequality of stress on the transverse and longitudinal joints of cylindrical boilers it has been proposed to arrange the joints diagonally (see figure 64). Taking the angle of the joints at 45°, the resultant of the transverse and longitudinal stresses per inch run of the joint is found by calculation to be nearly 80 per cent. of the greater stress, acting at an angle of about 72° to the joint.

Fig. 64.



J. G. Wright gives the strength of two specimens of single-riveted square lap-joints and two of diagonal joints, at an angle of 45°, which were tested by Kirkaldy. They were made of $\frac{3}{8}$-inch Staffordshire plate, exactly .38″ thick, 12″ wide, with $2\frac{1}{4}$″ lap, punched holes, and six $\frac{13}{16}$″ rivets in the square joint at 2″ pitch. The diagonal joint was made with eight rivets of the same size and pitch. The ultimate tensile strength of the solid plate was 19.69 tons per square inch with the fibre and 16.80 tons across. The sectional area of the entire plate was $(12 \times .38) = 4.56$ square inches. The net sectional area of the square joint was 2.71 square inches, and the shearing section of the rivets 3.11 square inches, or 115 per cent. of the net section.

	Ultimate tensile strength.		Net sectional area.		Net tensile strength per square inch of sectional area—per cent.
	Tons.	Per cent.	Square inches.	Per cent.	
Entire plate........	89.8	100	4.56	100	100
Square joint........	43.0	48	2.71	59.4	81.2
Diagonal joint......	58.0	64	3.98	87.2	73.4

It will be seen that the diagonal joint was one-third stronger than the square joint, although per square inch of net section it opposed less resistance.

An ingenious method of increasing the strength of a single-riveted joint—that of Webb—consists in having the rivets of oval section, and placed with their smaller diameters in a straight line parallel with the direction of the seam, and the transverse diameters parallel to each other and perpendicular to the direction of the seam, as in figure 65. The strength of this joint is claimed to be about 83 per cent. of the solid sheet; the smaller diameter of the rivets should be so large that they do not act as wedges in splitting the sheet. The alleged practical difficulties of manufacture disappear when the question is considered, for it would be easy to punch oval holes or to drill them with milling tools; the rivets also could be made in oval dies as well as in circular ones.

Still another method of strengthening a joint while retaining single-riveting is that of Beattie, who has patented a single-riveted joint over which is a covering-plate, also single-riveted, as seen in figure 66.

Fig. 65.

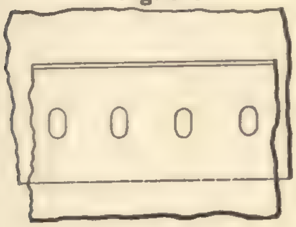
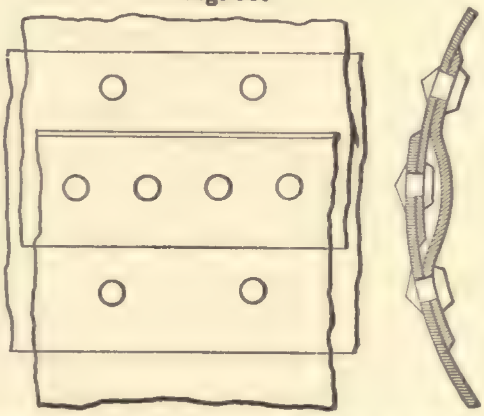


Fig. 66.



When it is difficult to set a sufficient number of single-shear rivets a forked arrangement, like that in figure 67, may be employed, making the riveting double-shear and of half the number.

A method of double-riveting which would greatly increase the strength of the joint,

Fig. 67.

Fig. 68.

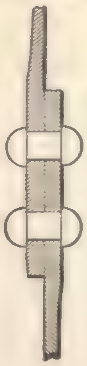
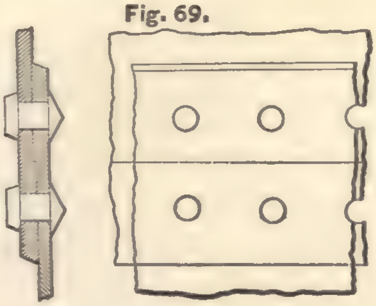


Fig. 69.



and even bring it to equality with that of the solid plate, has been proposed: it is to have the edges of the plates to be connected rolled thicker than the rest of the sheet,

as shown in figure 68, and Fairbairn has proposed further to add the thickness to the faying surfaces and to plane shoulders on each, so that they shall lock into each other —illustrated by figure 69. By these means the strength lost in the holes is restored, but the difficulty and expense of manufacture would probably prevent their general adoption.

17. Butt-joints.—The proportions of a *single-welt* butt-joint are the same as those of a lap-joint, as it is in effect equal to two laps in juxtaposition; the butt-strap is made equal in thickness to the sheets connected. Although single-welt butt-joints are not stronger than lap-joints, and are subject to the same distortion on account of the oblique action of the stress on the rivets, they are much used for large furnace-tubes subjected to an external pressure, where it is essential to preserve a perfectly cylindrical form; and for the transverse joints of cylindrical shells, which experience only one-half the stress borne by the longitudinal joints, and where a tight joint is more easily obtained with a single welt at places where the longitudinal and transverse joints meet; and in the flat heads of cylindrical boilers, where with thick plates smoother work can be made with butt-joints than with lap-joints, and where stiffness is of greater importance than tensile strength, since the direction of the principal strain is at right angles to the plate. The joint should be made with the butt-strap on the outside, so that it is accessible for subsequent calking, and that the action of the steam-pressure may assist in preventing the opening of the joint.

In the *double-welt* butt-joint the shearing of the rivets must occur in two places, and on this account their resistance is very nearly twice as great as in other joints. This joint is free from the distortion on account of the oblique action of the stress on the rivets to which the lap-joints and single-welt butt-joints are subjected, and for this reason it should be used for thick plates when practicable. Wilson says: "Besides the loss of strength due to the unequal distribution of the strain through the whole thickness of the plates in a lap-joint, very thick plates are also liable to be much reduced in strength through the body of the plate by injury done in the excessive amount of setting they require where the transverse and longitudinal seams cross each other. For this reason alone butt-joints should always be used, at least for the longitudinal seams with plates over $\frac{5}{8}$ inch thick. The width of the strap for double-riveting should be at least nine times the diameter of the rivet, and may with thick plates be made equal to ten times the diameter, the distance from the centre of the holes to the edge of the plates and straps in all cases being equal to the diameter of the rivet multiplied by $\frac{3}{2}$."

The butt-straps are made equal in thickness to at least one-half the thickness of the plates.

Applying the same notation as used heretofore the proportions of the double-welt butt-joints are found from the following equations:

SINGLE-RIVETED DOUBLE-WELT BUTT-JOINT.

To find the pitch of the rivets.

$$F = 2\,n\,d^2\,.7854\,S = n\,(p - d)\,t\,T;$$

$$p = \frac{1.5708\,d^2\,S}{t\,T} + d;$$

when $d = 1.05\,t$ (*see section* 13 *of the present chapter*) and $S = \frac{10}{9}\,T;$

$$p = 2.9\,d.$$

DOUBLE-RIVETED DOUBLE-WELT BUTT-JOINT.

To find the pitch of the rivets.

$$F = 4\,n\,d^2\,.7854\,S = n\,(p - d)\,t\,T;$$

$$p = \frac{3.1416\,d^2\,S}{t\,T} + d;$$

and when $d = 1.05\,t$ and $S = \frac{10}{9}\,T;$

$$p = 4.4\,d.$$

The following practice prevails at the Crewe Works (England), where Bessemer steel is used for locomotive boilers: "The joint of the barrel is made along the top, and is a single-riveted butt-joint, with inside and outside covering-strips. The barrel-plate is $\frac{7}{16}$ inch thick, the cover-strips $\frac{3}{8}$ inch thick by $5\frac{1}{4}$ inches wide; rivets $\frac{3}{4}$ inch diameter, spaced with 2 inches pitch and placed with the centres about $1\frac{1}{2}$ inches from the edge of the plate. This joint has been found to give 71.6 per cent. of the strength of the solid plate. The rivets are of steel. A noticeable feature in the proportioning of the joint is the distance of the rows of rivet-holes from the edges of the plate, this distance having been found necessary to prevent the distortion of the holes under strain. On the other hand, in the cover-strips, where there is an excess of strength, the holes come at an ordinary distance from the edge, so that there is no difficulty in calking properly." (*Engineering*, October 15, 1879.)

In practice it is convenient to have all the holes in the same sheet of equal size, and to use as small a variety of rivets as possible in the same boiler; on this account the diameters of rivets as found by the above formula are modified to suit these conditions. "The greatest difficulty in making a well-proportioned joint with the same-sized rivets occurs when butt-joints with double strips and lap-joints come together in the same plate. In such a case we must either sacrifice the advantage of having the same-sized

hole throughout the plate or have a badly-proportioned joint in one seam or the other. On this account, when double-fished butt-joints are used in the same plate with lap-joints, the former may be single and the latter double riveted, in which case the same pitch and diameter of rivet might be judiciously employed, were it not for the difficulty of keeping a tight joint in the butt arrangement, which necessitates the reduction of the pitch unless the workmanship is very good." (*Wilson.*)

TABLE XXIX.

WILSON'S TABLE OF PROPORTIONS OF DOUBLE-RIVETED BUTT-JOINTS WITH TWO COVERING-PLATES.

Thickness of plate. Inch.	Diameter of rivet. Inch.	Thickness of strap. Inch.	Pitch. Inches.	Thickness of plate. Inch.	Diameter of rivet. Inch.	Thickness of strap. Inch.	Pitch. Inches.	Thickness of plate. Inch.	Diameter of rivet. Inch.	Thickness of strap. Inch.	Pitch. Inches.
$\frac{3}{8}$	$\frac{5}{8}$	$\frac{1}{4}$	$2\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	3	$\frac{7}{8}$	1	$\frac{1}{2}$	$3\frac{5}{8}$
$\frac{7}{16}$	$\frac{5}{8}$	$\frac{1}{4}$	$2\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	$3\frac{1}{8}$	$\frac{15}{16}$	1	$\frac{1}{2}$	$3\frac{3}{4}$
$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{16}$	$2\frac{3}{4}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{7}{16}$	$3\frac{1}{4}$	1	$1\frac{1}{8}$	$\frac{9}{16}$	4
$\frac{9}{16}$	$\frac{11}{16}$	$\frac{5}{16}$	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{7}{16}$	$3\frac{1}{2}$				

In Kirkaldy's experiments on the comparative strength of chain and zigzag riveting in double-welt butt-joints, summed up in the 'Report of the Chief Engineer of the Manchester Boiler-Insurance Company for 1877,' the following statement occurs, tabulated herewith, showing that with chain-riveting greater strength is obtainable with smaller pitch—a great advantage in calking and making a tight joint. It will also be remarked that in both cases thicker plates, larger rivets, greater pitch, and drilled holes gave a smaller percentage of strength compared with the plate.

TABLE XXX.

Number of tests.	Thickness of plate. Inch.	Diameter of rivets. Inch.	Pitch of rivets. Inches.	Rivet-holes.	Ratio of strength of joint to plate. Per cent.	System of riveting.
2	$\frac{7}{16}$	$\frac{5}{8}$	$2\frac{1}{8}$	Punched....	67.2	Chain.
2	$\frac{7}{16}$	$\frac{5}{8}$	3	Punched....	66.9	Zigzag.
2	$\frac{1}{2}$	$\frac{3}{4}$	$2\frac{1}{4}$	Drilled	66.2	Chain.
2	$\frac{1}{2}$	$\frac{3}{4}$	3	Drilled	63.3	Zigzag.

The following table of the comparative strength of punched and drilled rivet-work, containing the result of Kirkaldy's experiments, is taken from the 'Proceedings of the Mechanical Engineers for 1872' and forms part of a paper read by W. R. Browne:

TABLE XXXI.

Description of joint.	Riveting.	Rivet-holes.	Proportions. Diameter of rivets to thickness of plates.	Proportions. Lap or cover to diameter of rivets.		Proportions. Pitch to diameter of rivets.	Ratio of strength of joint to that of plate, per cent.
				Lap.			
Lap	Single.	Punched..	2	3		3	55
		Drilled...	2	3		$2\frac{3}{5}$	62
				Chain.	*Zigzag.*		
Lap	Double	Punched..	2	$5\frac{1}{2}$	6	$4\frac{1}{2}$	69
		Drilled...	2	5	$5\frac{1}{2}$	4	75
				Covering-strip.			
Butt, 1 cover...	Single.	Punched..	2	6		3	55
		Drilled...	2	6		$2\frac{3}{5}$	62
				Chain.	*Zigzag.*		
Butt, 1 cover...	Double	Punched..	2	11	12	$4\frac{1}{2}$	69
		Drilled...	2	10	11	4	75
Butt, 2 covers..	Single.	Punched..	$1\frac{1}{4}$	6		$3\frac{1}{4}$	57
		Drilled...	$1\frac{1}{4}$	6		3	67
				Chain.	*Zigzag.*		
Butt, 2 covers..	Double	Punched..	$1\frac{1}{4}$	11	13	$5\frac{1}{4}$	72
		Drilled...	$1\frac{1}{4}$	10	12	$4\frac{3}{4}$	79

The experiments recorded in the following table have been selected from the 'First Report of the Committee of the Institute of Mechanical Engineers on the Form of Riveted Joints.' The stresses corresponding to the actual mode of fracture are printed in heavy type; the other stresses, printed in ordinary type, are those which obtained at the moment of fracture, but are lower than those at which the joint would have given way by the respective modes of fracture. The joints marked *d*, *e*, and *f* in the table, and their lines of fracture, are represented in figures 70, 71, and 72 respectively. The steel plates had a nominal thickness of $\frac{7}{8}$ inch. The butt-straps were $\frac{9}{16}$ inch thick, and the steel rivets had a diameter of 1.13 inches. The tensile strength of the rivets was

28.9 tons per square inch, and the apparent shearing strength of the rivets in experi-

Fig. 70.

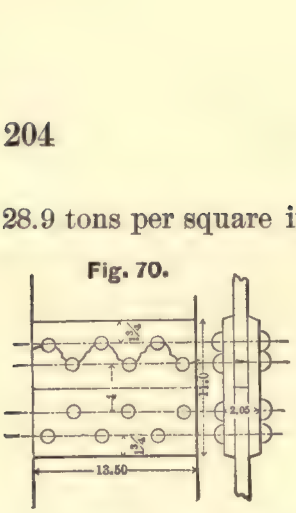


Fig. 71.

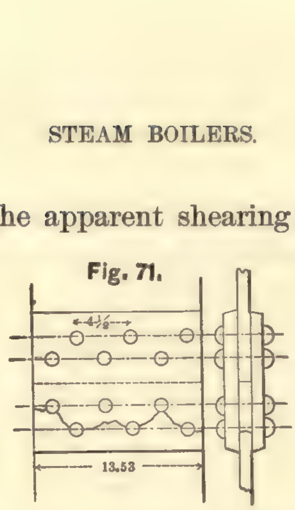
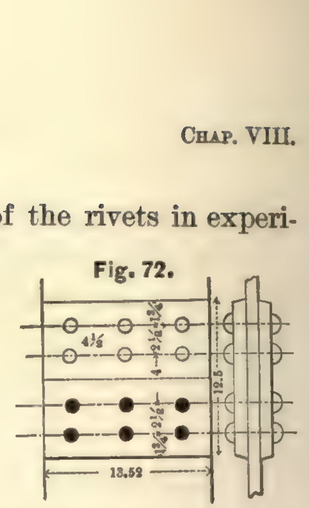


Fig. 72.



ment f was, therefore, 68.5 per cent. of their tenacity. In experiments d and e the plates broke on the line marked in figures 70 and 71.

TABLE XXXII.

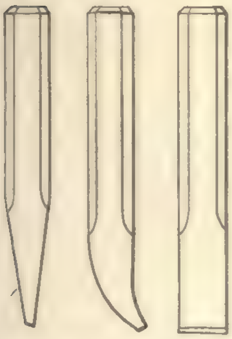
RESULTS OF EXPERIMENTS WITH SINGLE AND DOUBLE-RIVETED DOUBLE-WELT BUTT-JOINTS.

Mode of riveting.	Holes.	Kind of plates and rivets.	Tenacity of solid plates in tons per square inch.	Stress at moment of fracture in tons per sq. in.			Apparent tenacity of joint in per cent. of tenacity of solid plate.	Efficiency of joint, per cent.	Remarks.
				Tensile.	Shearing.	Crushing.			
Single-riveted	Punched	Iron plates and rivets.	25.77	**24.31**	16.38	43.09	94	60	Mean of three experiments by Fairbairn.
"	Drilled	"	22.25	**24.24**	11.48	33.83	109	63	Greig and Eyth.
"	"	Steel plates and rivets.	36.22	36.62	**18.75**	52.94	101	60	Henry Sharp.
Double-riveted	Punched	Iron plates and rivets.	25.77	**21.44**	10.82	25.17	83	67	Mean of two experiments by Fairbairn.
"	Drilled	"	22.25	**20.65**	8.92	25.72	93	64	Greig and Eyth.
"	Punched	"	19.35	**17.52**	6.90	13.00	91	54	Plates 1 inch thick. Two experiments, R. V. J. Knight.
"	Drilled	Steel plates and rivets.	36.22	**42.93**	13.16	37.20	119	70	Henry Sharp.
"	Punched	"	36.22	**39.11**	11.57	33.56	108	63	
"	"	"	36.20	**33.75**	15.30	41.39	93	64	Mean of ten experiments. Plates annealed. D. Kirkaldy.
Double-riveted (zigzag) (d).	Drilled and reamed.	"	28.10	**20.04**	16.40	21.92	71	59	
" " " (e).	Punched and ream'd	"	27.10	**22.73**	16.80	22.66	84	63	David Kirkaldy. Plates ⅝ inch thick.
Double-riveted (chain) (f)..	Drilled and reamed.	"	28.20	27.23	**19.80**	27.10	....	72	

18. Calking.—Since the surfaces of boiler-plates are always more or less rough, the riveted joints require calking to make them steam and water tight. Calking consists in bringing the extreme edge of one boiler-plate so close to the solid part of the other that there shall be no leakage between the two. Calking should always be done on both

sides, where it is possible to do so. If the riveting has not entirely closed the extreme edge a heavy hammer has to be used to do this. Wedges or pieces of hoop-iron should never be driven between the laps, nor should sal-ammoniac or any other substance be used to make the joint tight by rusting. If the edge of the plate has not already been planed it should be chipped smooth to an angle of about 110°. The tools ordinarily in use are represented in figure 73.

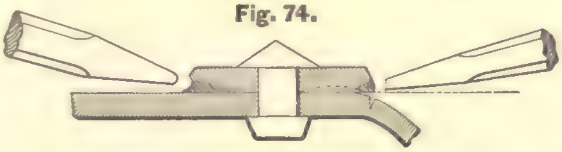
Fig. 73.



The bevel of the calking-tool should be about 20°, the sharp corner being first used for making a slight indentation in the lap-edge—this operation is called splitting the lap; then the tool is turned and the whole width is used for driving in or upsetting the edge against the sheet. Care must be taken not to move the calking-tool its entire breadth after each blow, else small places will be left uncalked; one hard blow at each place should be sufficient. Sexton says that the proper thickness for a calking-tool for plates from $\frac{3}{8}$ inch to $\frac{7}{8}$ inch thick is $\frac{3}{16}$ inch; for plates more than $\frac{7}{8}$ inch thick the tool should be $\frac{1}{4}$ inch.

Connery's calking-tool is made convex, so that it shall not cut the metal. The comparative working of the two tools is shown in the sketch (figure 74), which, however, is somewhat exaggerated; the old method, shown to the right, is to chip or plane the edge of the lap, then to drive up the tool, indenting the lower sheet and tending to curve the lap upward as shown in dots; if afterward the lower sheet be bent, either purposely or by the action of unequal expansion, grooving ensues at the indentation caused by the tool. With the concave tool a depression is made in the edge of the lap, and the lower portion of the lap is driven against the other sheet without injuring the latter; the comparative extent of compression in the two methods is said to be shown by the wedge of dark shading in the two cases.

Fig. 74.



The butt is calked with the tool delineated in figure 75, which makes an indentation as sketched at figure 76.

Boilers should not be calked under pressure, as the jarring would probably start leaks in seams elsewhere. Excessive calking of lap-joints works mischief in several ways: thin plates may be forced apart when a set and heavy hammer are used—this is shown in figure 57; when the edge of the calking-tool is very thin it sometimes acts as a wedge, forcing the joint wide open. In contrast with the foregoing, figure 77 is given

from Burgh's 'Practical Treatise,' which he calls "an illustration of the result of proper drilling, fitting, riveting, and calking."

Fig. 75.

Fig. 76.

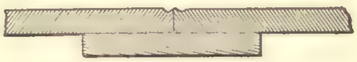
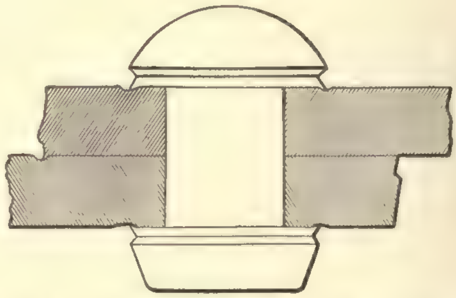


Fig. 77.



19. Welding.—Nasmyth says of welding that it consists in inducing upon malleable iron, by means of a very high heat, a certain degree of adhesion, so that any two pieces of malleable iron, when heated to the requisite degree, will, if brought into close contact, adhere or stick together with a greater or less tenacity, according to the amount of force applied to urge them into close contact. . . . The chief cause of defective welding arises from portions of the vitreous oxide of the iron being shut up between the surfaces at the part presumed to have been welded; and since, besides the impossibility of ascertaining in the majority of cases, after the process of welding has been gone through, whether or not this vitreous oxide has been thoroughly expelled and the surfaces at the welding brought into perfect metallic union, no after-heating or hammering can dislodge the vitreous oxide when once it has effected a lodgment, our best and only true security is to form the surfaces of the iron, at the part where the welding is desired to take place, so that when applied to each other when at the welding-heat *their first contact with each other shall be in the centre of each.*

Much attention has been paid of late to the effect of chemical composition on the welding of iron. D. Adamson states in his paper read before the Iron and Steel Institute, September, 1878: "After many trials and many failures in attempting to weld steel boiler-plates the writer found it necessary to ascertain in all cases the composition of the metal before putting any labor upon it, and from a large experience it is now considered desirable that the carbon should not exceed 0.125 per cent., while the sulphur and phosphorus should, if possible, be kept as low as 0.04 per cent., silicon being admissible up to the extent of 0.1 per cent."

A. L. Holley, in a paper read before the American Institute of Mining Engineers in February, 1878, discusses the results obtained by the United States Test-Board in experiments upon fourteen brands of wrought-iron intended for chain-cables. He comes

to the following conclusions, viz.: "Phosphorus up to the limit of one-quarter per cent. had not a notable effect on welding." "Carbon notably affected welding. It ran in connection with regularly decreasing welding power from 0.02 to 0.35 per cent." "Carbon, in a greater degree than phosphorus, promotes fluidity; hence the iron is burned at the ordinary welding temperature of low-carbon irons." "Slag should theoretically improve welding, like any flux, but its effects in these experiments could not be definitely traced." "The experiments prove that the strength of the link, which is chiefly dependent on welding power, as compared with the bar was more decreased by overworking (in reducing the pile to the bar) than by any other cause, excepting the high carbon in the steely iron L and the excessive copper, phosphorus, etc., in the peculiar iron M." Regarding the strength of the welded joint of the latter iron he says: "Its surfaces were pretty well united by welding, but the iron about the weld was weakened, especially at a high heat. Of 59 ruptures of links made of this iron, 33 were through the weld and the iron was little distorted. Of 303 ruptures of links made of other irons, but 36 were through the weld."

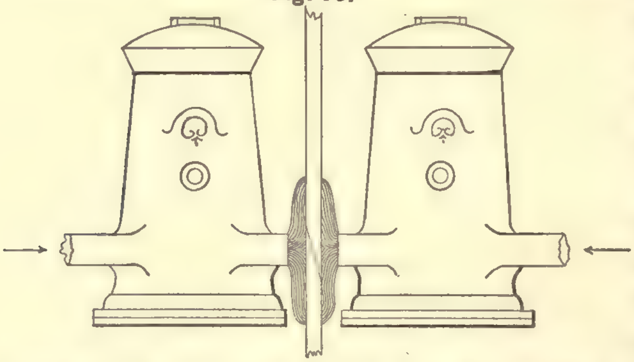
He proposes the following theory regarding welding: "It is certain that perfect welds are made by means of perfect contact due to fusion, and that nearly perfect welds are made by means of such contacts as may be got by partial fusion in a non-oxidizing atmosphere or by mechanical fitting of the surfaces, *whatever* the composition of the iron may be within all known limits. While high temperature is thus the first cause of that mobility which promotes welding, it is also the cause, in an oxidizing atmosphere, of that '*burning*' which injures both the weld and the iron. Hence welding in an oxidizing atmosphere must be done at a heat which gives a compromise between imperfect contact due to want of mobility on the one hand and imperfect contact due to oxidation on the other hand. This heat varies with each different composition of irons. It varies because these compositions change the fusing-points of irons, and hence their points of excessive oxidation. Hence, while ingredients such as carbon, phosphorus, copper, etc., positively do not prevent welding under fusion or in a non-oxidizing atmosphere, it is probable that they impair it in an oxidizing atmosphere, not directly but only by changing the susceptibility of the iron to oxidation.

"The obvious conclusions are: 1st. That any wrought-iron, of whatever ordinary composition, may be welded to itself in an oxidizing atmosphere at a certain temperature, which may differ very largely from that one which is vaguely known as '*a welding-heat*.' 2d. That in a non-oxidizing atmosphere heterogeneous irons, however impure, may be soundly welded at indefinitely high temperatures."

20. Welding Boiler-plates.—The welding of boiler-plates was first successfully

tried by W. Bertram, at Woolwich Dockyard, in 1857. His method is represented in figure 78. The edges of the plates are scarfed and placed together; two non-oxidizing gas-flames are obtained by the combustion of coal or coke in suitable furnaces, and these are directed against either side of the plates until they are raised to a welding-heat, when they are united by pressure or hammering. For this purpose a number of stampers are sometimes used — viz., upright rams raised by four-toothed cams and falling by their weight upon the work, which is placed on an anvil. The work is said to be done three or four times as expeditiously as hand-riveting.

Fig. 78.



The scarf-weld, either of the form shown in figure 78 or else prepared as drawn in figure 79, is much stronger than the lap-welded joint, which is shown in figure 80, since

Fig. 79.

Fig. 80.

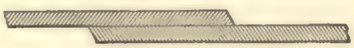
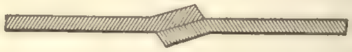


Fig. 81.



the strain on the scarfed joint is direct, instead of tending to spring the joint as with the lap-welded plates shown in figure 81. The lap-weld should be used, on this account, only with very thin plates. The welded joints of thicker plates might be greatly increased in strength by a covering-plate, as shown in figure 82.

The seams of the flues of high-pressure boilers are frequently welded in the manner

Fig. 82.

Fig. 83.

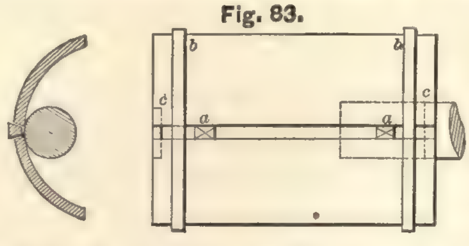
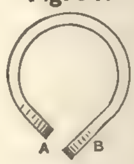


Fig. 84.



illustrated in figure 83. The edges of the bent sheet are kept apart, a distance of about $\frac{5}{8}$ inch, by small blocks, *a a*, the sheet being held together by the bands *b b*, secured by bolts and nuts. A narrow strip, *c c*, is welded over the seam to the plates at each end, in order to hold them more securely in position. The two edges and a rod of a wedge-shaped or round section are brought to a welding-heat in an open fire; the tube is passed over the long horn of an anvil, the rod is inserted between the edges, and all

three parts are welded by hammering for a distance of a few inches. Then the nearest band and block are moved along, the rod is cut, another heat is taken, and the process is repeated. In small tubes where pressure by machinery can be applied the weld can be made with a butt-joint.

The following practical points in reference to welding are selected from Sexton's 'Boiler-makers' Pocket-book.' Pipes or cylinders up to four feet diameter may be easily welded in the following manner: Bend the pipe or cylinder in the form of figure 84, the edges A and B not touching by about a quarter of an inch; place it on a clear fire, throw a little sand and scale on the edges, turned downward; place a fire-brick on the part through which the greatest heat is coming. The brick is a very slow conductor of heat, and will greatly assist the iron in getting hot, as it does not absorb much heat itself. The blast is started moderately till the iron becomes of a pale yellow, then put on strongly till the iron is white-hot, when the work is brought out and placed on the mandrel as quickly as possible. The first blow should fall gently on the edge A, and B is hammered down on it; and when the iron has cooled so as not to fly to pieces under the blows these are repeated as hard and quickly as possible until the edge has disappeared and a smooth surface is left. There is also an arrangement of a forge on wheels made to run inside the cylinder with an india-rubber blast-pipe connected to it, and when the lap of the plate is sufficiently heated the forge is withdrawn and an anvil wheeled in its place.

Fig. 85.

In welding the longitudinal seams of a boiler one inch thick, with four plates to the circle, the plates are punched for the circumferential seams, but not quite to the longitudinal edges; these last are then planed to an angle of 45°; then, after being rolled and set, the plates are fastened together temporarily with the planed edges inside. These edges are heated in a clear fire at the same time that a piece of square iron is heated in a separate fire, and, when sufficiently heated, the boiler, suspended from a suitable crane, is brought out, placed on the block, the square iron, which is rather hotter than the plates, laid in cornerwise, as at C in figure 85, and hammered direct on the upper corner. Six or seven inches at a heat will be sufficient to weld. The weight of the ring of plates must not rest on the block, or it will become flat.

The bar should have its sides equal in width to the planed edge of the plate. The welding should be commenced in the middle and worked towards the ends, which are kept securely bolted as long as is necessary. In putting the rings together the welded seams should break joint. In furnace-tubes the weld should be below the grate.

When it is desirable to have the front of a boiler in one piece but a plate of sufficient size cannot be procured, two plates may be welded together, either by laying in a square bar, as in figure 86, or by thickening both edges, splitting one and tapering the

Fig. 86.

Fig. 87.

Fig. 88.

other, as sketched in figure 87, then forcing one into the other, as shown in figure 88; this form, however, is not favorable for the escape of the scale, and the difference in thickness of the edges in the fire is not favorable for the iron being properly and uniformly heated. It is more applicable for welding bars and plates of very short length. The plates are secured by several short pieces of angle-iron bolted to them, and by as many turn-buckles and chains as the length of the work requires (see figure 89), then placed in the fire so as to heat the edges in question. When the plate is hot the expansion of the metal acting against the strain of the screws will weld the plates even before they are hammered on the block, which, of course, must be done when sufficiently heated.

Fig. 89.

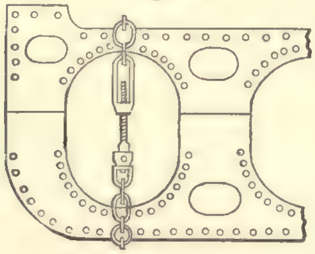


Fig. 90.

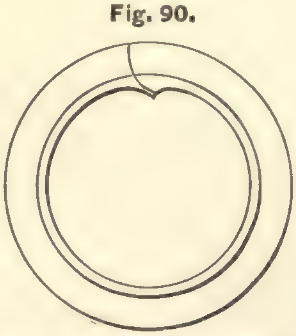
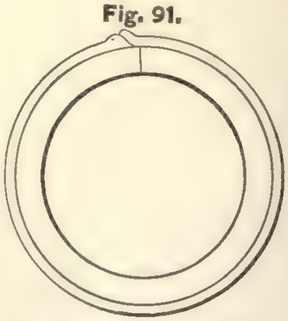


Fig. 91.



"In welding angle-iron rings for flanging, for strengthening flues, etc., the ends are upset and scarfed or bevelled on the side required; then, a short heat being taken, about six inches at each end are bent; next, as long a heat as possible being got, the ring is bent around a shaper to the required curve. The ends of an external ring should have the lump inside before welding, as in figure 90, since this ring must be hammered on the inside during the welding process; while in the internal ring, figure 91, the lump is left on the outside, that being the side on which the ring is most hammered.

"In making up a fire for welding, as the article in question is not to be made hot all

over, but only at the part to be welded, the size of the fire should be limited to that portion. For complicated shapes the small coal may be wet and built up around the object or a rude pattern of it, and, the latter being withdrawn, the hole filled with clean hot coke, together with small fresh coke ; next, the object being put in position, some sand is sprinkled on the edges to be welded, which are then covered with a fire-brick, the blast is started gently, and wet coal built up around what soon becomes a hollow fire ; this should be disturbed as little as possible, and only to watch its progress. The blast is presently increased, and when the sand is melted, and the metal white and beginning to emit brilliant white sparks, the work may be brought out, and no time must then be lost in the welding, all tools being in place and preparations made beforehand."

One of the advocates of welding says : "Among the difficulties of welding plates are that they heat unequally, buckle, blister, and frequently become exposed while hot to the air for a space of time sufficient to provide a coat of oxide fatal to the future joint. But by the adoption of this principle we could reduce the thickness of boiler-plates by one-half, rendering them lighter and more easily worked and handled in every way. The expense incurred should not be higher than that of the riveted joint ; the extra trouble of fitting and scarfing would not equal that of punching, and the fuel consumed in rivet making and heating would nearly suffice for welding. There are certain situations in a boiler where this process would be inapplicable and where rivets would have to be used. In early experiments a seam 12 feet long in $\frac{3}{8}$-inch plates was welded in one hour and twenty minutes with mouth-pieces or nozzles only 6 inches long."

21. Strength of Welded Plates.—Wilson gives the result of some experiments recorded by Kirtley on the tensile strength of strips cut across the weld and taken from several boilers with welded longitudinal seams ; the strips were $7\frac{1}{2}$ inches long and $\frac{7}{16}$ inch thick :

Width of strip.	Number of strips tested.	Broke in weld.	Broke in solid.	Breaking strength in tons per square inch.		
Inch.				Least.	Greatest.	Mean.
1	15	8	7	16.5	23.8	20.2
$1\frac{3}{8}$	4	2	2	19.6	22.2	21.0
$1\frac{1}{2}$	4	1	3	18.1	23.5	21.7
Total	23	11	12	16.5	23.8	20.6
11 strips of the same plates unwelded........				20.7	25.8	23.6

After giving the foregoing table he proceeds : "It appears from these results that

half of the test-pieces broke in the solid, and not at the weld. The average loss of strength of the 23 welded plates was only 12.7 per cent. compared with the strength of the 11 unwelded plates; the worst pieces, showing as defective a weld as would occur in practice, had 70 per cent. of the average strength of the unwelded plates. The weld is best made when the edges of the plates are upset at a red-heat, by hammering or pressure, to nearly double their thickness, and bevelled to an angle of about 45°. The edges can then be heated simultaneously, and the weld made by hammering down the joint to the original thickness of the plate. In some cases it has been found that the plates are rapidly pitted at the weld." This is doubtless owing to the outer protecting film or skin being removed by the fire and working.

"Some time ago Mr. Gillott, of Farnley, who has had great experience in smithing boiler-plates, had reason to suspect that in welding boiler-tubes in successive heats and in short lengths after the ordinary manner there is a straining action upon the length already welded, owing to the expansion under heat of the adjacent length being welded, and we are indebted to Mr. Gillott for the following results of some experiments he made. In order to ascertain the correctness of his views he took a welded and flanged tube 2 feet 8 inches in diameter, 3 feet long, of $\frac{7}{16}$-inch best Yorkshire plate, welded by hand-hammers, and in every respect a fair average job. The plate was prepared for welding with a "*bent scarf*," so that the finished work was generally somewhat thicker, or at any rate not less, than the solid plate. The welding was commenced at the middle of the plate and worked towards each end. The tube was put in a lathe, and a length of about 5 inches was cut off one end. Six rings were then cut off about 2 inches wide and numbered consecutively 1 to 6, counting from the edge where the 5-inch length was cut off, so that the piece marked 6 would be about the original middle of the plate. Strips 2 feet 6 inches long, having the weld approximately in the centre, were cut from each ring, and similar strips of the solid plate also. The strips were then all heated and carefully straightened." . . . "The strips were then tested by being pulled asunder, with the results given in the annexed table." . . . "Not only the strength but the ductility of the weld diminished progressively from the end to the middle portion of the plate, or from the part last welded to that which was first welded." All strips broke at the weld.

"In a furnace-tube, where the pressure tends to assist in keeping the weld together, the limited tensile strength due to the unsoundness of the weld may be outweighed by other advantages, as for flanging, etc., which the welding gives; but for the longitudinal seams of boiler-shells the uncertainty of making a sound and strong weld, when the job is done in lengths, renders it difficult to conclude otherwise than that such welding

is not so good as riveting, notwithstanding the liability of the latter to leak. This conclusion does not apply to joints where the weld is completed at one heat by pressure either with rolls or otherwise." (*Engineering*, January 31, 1879.)

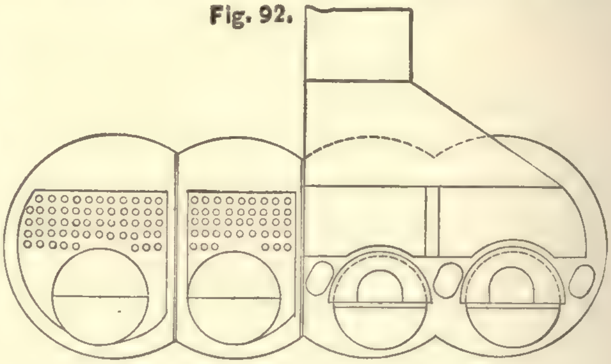
Mark.	W_1	W_2	W_3	W_4	W_5	W_6	Average result for strips of solid plate.
Breaking weight, in tons per sq. in. of original area......	Broke at weld, but bent laterally owing to shackle slipping.	19.48	18.73	17.67	16.3	14.84	23.34
Elongation per cent. in 18 inches.		9.375	6.597	6.25	4.166	3.472	17.71

CHAPTER IX.

SHELL, FURNACES, AND BACK-CONNECTIONS.

1. Various Forms of Shells.—The forms commonly given to the shell of marine boilers have been described and illustrated in section 3, chapter vii. These forms are produced by combining flat and cylindrical plates in various ways. Figure 92 illustrates one form of the "*connected-arc marine boiler*" of C. E. Emery, who states that "the object of the invention is to construct steam boilers of great strength, with the minimum amount of small stays or braces, and in such form as to occupy less room for a given power than ordinary cylindrical boilers; also to obtain, when desirable, a large boiler of moderate height."

Fig. 92.



When such a boiler is braced according to the rules given in section 7, chapter vi., the plates forming the several arcs experience only a tensile strain, like the circular shell of a cylindrical boiler, while the flat surfaces of boilers are subjected to bending strains.

The thickness of the plates forming the cylindrical portions of the shell is found by formula [III.], section 2, chapter vi., by making the value of k equal to the ultimate strength of the joints divided by a factor of safety; the strengths of various joints relatively to the strength of the entire plate, as determined by experiment, are given in sections 15 and 17, chapter viii.

The strength of the flat surfaces of the shell of boilers depends almost entirely on the bracing and staying, the plates being made thick enough to give them proper stiffness. Plates less than one-quarter inch thick cannot be calked efficiently, and are therefore not used for boiler-shells. Tight joints cannot well be made by riveting together plates varying greatly in thickness; on this account the thickness of the flat plates of the shell does not vary generally more than one-eighth inch from that of the cylindrical plates. Various methods of, and rules for, staying the flat surfaces of boilers will be found in chapter x.

In places where holes are cut in the shell for handholes, manholes, etc., stiffening-

plates or angle-irons are riveted around the opening. In cylindrical shells, depending on their form for strength, it is important that these compensating-rings do not only stiffen the weakened parts, but provide at any section at least the same amount of metal as has been lost in making the opening. In the boiler illustrated on Plate XII. the butt-straps serve also as strengthening-plates around the manholes and where tie-rods pass through the front-head.

It is recommended to place the larger axis of manholes in a transverse direction on circular shells, so that the least metal is cut away in the direction in which the stress on the shell is greatest.

The precautions to be taken when steam-domes are placed on cylindrical shells will be discussed in section 2, chapter xiii.

For the shell of boilers an inferior sort of iron is often used, known as "*shell-iron*," which does not flange well; but for the boilers of United States naval vessels it is always stipulated that all parts shall be constructed of the best charcoal flange-iron.

2. Rectangular Shells.—The form of boilers generally used in vessels of the United States Navy, in cases where the steam-pressure does not exceed 45 lbs. above the atmosphere, is illustrated on Plates III., VI., VII., and XVII. The top, bottom, sides, front, and back of the shell are flat; but the sheets joining the top to the sides, front, and back, and the sides and back to the bottom, are bent to as large a radius as the internal arrangement of the boiler admits. By giving to the lower part of the boiler the form shown on Plate XVII. there is not only a useless space in the boiler omitted, but a great additional advantage is often gained in narrow vessels, since, with the fire-room running in a fore-and-aft direction between the boilers, these can be placed much farther outboard. Rectangular boilers are often made without water-bottoms (see Plates VI., VII.); this form will be described in section 5 of the present chapter.

The thickness of the plates of rectangular boiler-shells varies ordinarily from $\frac{5}{16}$ to $\frac{7}{16}$ inch, according to their location, the steam-pressure, and the arrangement of the stays and braces. The plates forming the lower portion of the shell exposed to the corrosive action of the bilge-water are made $\frac{1}{16}$ or $\frac{1}{8}$ inch thicker than the rest. Lap-joints are generally employed throughout the shell of rectangular boilers, and these should be double-riveted. The laps are sometimes slightly bent, one inward and the other outward, so as to keep the sheets forming a flat surface in the same plane; by giving in this manner to the lap-joints the form which they tend to assume under pressure the joints are less severely strained (see figure 46). Care must be taken that the laps of contiguous sheets break joint, and that they are accessible for calking. In the horizontal joints of the sides, front, and back the lap of the upper end of each sheet is placed

on the outside of the boiler; this prevents the loose scale from lodging on the laps inside the boiler. The square corners connecting the sides, front, and back of the boiler are formed by turning flanges on the sheets. The practice of forming these corners by angle-irons placed inside the boiler, to which the plates are riveted, permits the use of an inferior iron for the shell, but is not to be recommended.

Plates VI., VII., XVII. illustrate fully the construction of the shell of rectangular boilers, showing the size and shape of the plates and the manner of forming the flanges and joints. An English practice of welding the plates forming the boiler-front has been described and illustrated in chapter viii.

3. Cylindrical Shells.—Cylindrical shells are generally built up by joining together several rings or belts. The plates forming these belts are so arranged that the fibre of the iron runs in a circumferential direction. When plates of moderate thickness are used the longitudinal seams are often formed by double-riveted lap-joints; it is, however, better to use double-riveted butt-joints with an inner and outer covering-plate. Sometimes these rings are formed by welding the plates together. In connecting these several belts care must be taken that the longitudinal seams of adjoining belts are placed as far apart as possible.

The transverse joints connecting these belts are either lap or butt joints. When the belts are connected by lap-joints it may be advantageous to place them telescopically, as shown in figure 18, in short cylindrical boilers with few widths, since that arrangement tends to drain the mud and dampness toward the large end, where cocks, hand-holes, or other provisions may be made for cleaning. When the boilers are long the sheets are alternately outside and inside, or raised and sunken. When a single butt-strap is used for the transverse joints it must be placed on the outside of the shell, in order to make it accessible for calking; the inner longitudinal butt-straps must lap over on the adjoining sheets, so that the ends of these straps may be calked properly (see Plate XIII.) Single butt-straps give ample strength for the transverse joints of shells; sometimes, however, a thin inner strap is added, in order to give facilities for calking the joint more thoroughly from the inside. It is well to put a rivet through the seam at places where the longitudinal and transverse joints meet, in order to close them effectually against any leakage. The ends of the transverse butt-straps are made to lap over one another, the inner end being properly scarfed. The riveting of these transverse straps to the belts is commenced at their middle, so that any slack may be worked into the seam. Where the longitudinal straps are crossed by the transverse straps their ends are scarfed, so that they all lie close together and against the shell, and the transverse strap requires less setting.

The front and back heads of large boilers are flat, and are flanged in order to connect them to the shell. In small boilers these flanges are often placed outside the shell when the space inside the boiler is too contracted to be accessible for riveting; but in large boilers these flanges are turned inside the boiler, so that the joint can be calked inside and outside. Angle-irons are sometimes used to make this connection. The heads of large boilers are necessarily composed of several plates, connected either by lap-joints or by butt-joints. When lap-joints are used the laps of the same plate are either placed one inside and the other outside, or the plates are placed in alternate inside and outside courses. When the plates composing the heads are thick it is best to unite them by means of a double-riveted single butt-strap placed on the outside. The ends of the butt-strap are bent with the flange of the head and thinned, the cylindrical shell being set out, where it covers the strap, in order to make a close-fitting, tight joint.

'Lloyd's Register of British and Foreign Shipping' prescribes the following "Rules for Determining the Working Pressure in New Boilers":

Cylindrical Shells.—The strength of circular shells to be calculated from the actual strength of the longitudinal joint by the following formula:

$$\frac{C \times T \times B}{D} = \text{working pressure},$$

where C = constant as per following table;

T = thickness of plates in inches;

D = mean diameter of shell in inches;

B = percentage of strength of joint found as follows—the least percentage to be taken:

For plate at joint $B = \dfrac{p - d}{p} \times 100$;

For rivets at joint $B = \dfrac{n \times a}{p \times T} \times 100$ with punched holes;

$$B = \frac{n \times a}{p \times T} \times 90 \text{ with drilled holes}$$

(in case of rivets being in double-shear 1.75 a is to be used instead of a);

where p = pitch of rivets;

d = diameter of rivets;

a = sectional area of rivets;

n = number of rows of rivets.

NOTE.—In steel boilers it is required that the strength of the rivets used to resist

shearing should be shown to be at least 26 tons per square inch. If it is less than 26 tons per square inch the rivet-area should be proportionately increased.

TABLE OF CONSTANTS.

IRON BOILERS.

Description of longitudinal joint.	For plates ½ inch thick and under.	For plates ¾ inch thick and above ½ inch.	For plates above ¾ inch thick.
Lap-joint, punched holes................	155	165	170
" drilled holes..................	170	180	190
Double butt-strap joint, punched holes....	170	180	190
" " drilled holes......	180	190	200

STEEL BOILERS.

Description of longitudinal joint.	For plates ⅜ inch thick and under.	For plates 9-16 inch thick and above ⅜ inch.	For plates ¾ inch thick and above 9-16 inch.	For plates above ¾ inch thick.
Lap-joints.............................	200	215	230	240
Double butt-strap joints..................	215	230	250	260

NOTE.—The inside butt-strap to be at least three-quarters the thickness of the plate.

For the shell-plates of superheaters or steam-chests exposed to the direct action of the flame the constants should be two-thirds of those given in the above tables.

Proper deductions are to be made for openings in shell.

All manholes in circular shells to be stiffened with compensating-rings.

The shell-plates under domes in boilers so fitted to be stayed from the top of the dome or otherwise stiffened.

The 'Surveyors of the Board of Trade' (England) are guided in the inspection of boilers by the following rules:

"When cylindrical boilers are made of the best material, with all the rivet-holes drilled in place and all the seams fitted with double butt-straps, each of at least five-eighths the thickness of the plates they cover, and all the seams at least double-riveted with rivets having an allowance of not more than 50 per cent. over the single-shear, and provided that the boilers have been open to inspection during the whole period of construction, then six may be used as the factor of safety; but the boilers must be tested by hydraulic pressure to twice the working pressure in the presence and to the satisfaction of the Board's surveyors. But when the above conditions are not complied with the

additions in the following scale must be added to the factor six, according to the circumstances of each case:

A	.15	To be added when all the holes are fair and good in the longitudinal seams, but drilled out of place after bending.
B	.3	To be added when all the holes are fair and good in the longitudinal seams, but drilled out of place before bending.
C	.3	To be added when all the holes are fair and good in the longitudinal seams, but punched after bending, instead of drilled.
D	.5	To be added when all the holes are fair and good in the longitudinal seams, but punched before bending.
E*	.75	To be added when all the holes are not fair and good in the longitudinal seams.
F	.1	To be added if the holes are all fair and good in the circumferential seams, but drilled out of place after bending.
G	.15	To be added if the holes are fair and good in the circumferential seams, but drilled before bending.
H	.15	To be added if the holes are fair and good in the circumferential seams, but punched after bending.
I	.2	To be added if the holes are fair and good in the circumferential seams, but punched before bending.
J*	.2	To be added if the holes are not fair and good in the circumferential seams.
K	.2	To be added if double butt-straps are not fitted to the longitudinal seams, and the said seams are lap and double riveted.
L	.1	To be added if double butt-straps are not fitted to the longitudinal seams, and the said seams are lap and treble riveted.
M	.3	To be added if only single butt-straps are fitted to the longitudinal seams, and the said seams are double-riveted.
N	.15	To be added if only single butt-straps are fitted to the longitudinal seams, and the said seams are treble-riveted.
O	.1	To be added when any description of joint in the longitudinal seams is single-riveted.
P	.1	To be added if the circumferential seams are fitted with single butt-straps and are double-riveted.
Q	.2	To be added if the circumferential seams are fitted with single butt-straps and are single-riveted.
R	.1	To be added if the circumferential seams are fitted with double butt-straps and are single-riveted.
S	.1	To be added if the circumferential seams are lap-joints and are double-riveted.
T	.2	To be added if the circumferential seams are lap-joints and are single-riveted.
U	.25	To be added when the circumferential seams are lap and the streaks or plates are not entirely under or over.
V	.3	To be added when the boiler is of such a length as to fire from both ends, or is of unusual length, such as flue-boilers; and the circumferential seams are fitted as described opposite P, R, and S; but, of course, when the circumferential seams are as described opposite Q and T, V.3 will become V.4.
W*	.4	To be added if the seams are not properly crossed.
X*	.4	To be added when the iron is in any way doubtful and the surveyor is not satisfied that it is of the best quality.
Y	1.65	To be added if the boiler is not open to inspection during the whole period of its construction.

"Where marked * the allowance may be increased still further if the workmanship or material is very doubtful or very unsatisfactory

"The strength of the joints is found by the following method:

$$\frac{(\text{Pitch} - \text{diameter of rivets}) \times 100}{\text{Pitch}} = \left\{ \begin{array}{l} \text{Percentage of strength of plate at joint} \\ \text{as compared with the solid plate.} \end{array} \right.$$

$$\frac{(\text{Area of rivets} \times \text{No. of rows of rivets}) \times 100}{\text{Pitch} \times \text{thickness of plate}} = \left\{ \begin{array}{l} \text{Percentage of strength of rivets as} \\ \text{compared with the solid plate.*} \end{array} \right.$$

"Then take iron as equal to 23 tons, and use the smallest of the two percentages as the strength of the joint, and adopt the factor of safety as found from the preceding scale:

$$\frac{\begin{pmatrix} \text{51520} \times \text{percentage of} \\ \text{strength of joint.} \end{pmatrix} \times \begin{pmatrix} \text{twice the thickness of} \\ \text{the plate in inches.} \end{pmatrix}}{\text{Inside diameter of the boiler in inches} \times \text{factor of safety}} = \left\{ \begin{array}{l} \text{Pressure to be allowed per} \\ \text{square inch on the safe-} \\ \text{ty-valves.} \end{array} \right.$$

"Plates that are drilled in place *must* be taken apart and the burr taken off, and the holes slightly countersunk from the outside.

"Butt-straps *must* be cut from plates and *not* from bars, and must be of as good a quality as the shell-plates, and for the longitudinal seams *must* be cut across the fibre. The rivet-holes may be punched or drilled when the plates are punched or drilled *out* of place, but when drilled in place must be taken apart and the burr taken off, and slightly countersunk from the outside.

"When single butt-straps are used, and the rivet-holes in them punched, they *must* be one-eighth thicker than the plates they cover.

"The diameter of the rivets *must not* be less than the thickness of the plates of which the shell is made; but it will be found when the plates are thin, or when lap-joints or single butt-straps are adopted, that the diameter of the rivets should be in excess of the thickness of the plates. Dished ends that are not truly hemispherical must be stayed; if they are not theoretically equal in strength to the pressure needed they must be stayed as flat surfaces, but if they are theoretically equal in strength to the pressure needed the stays may have a strain of 10,000 lbs. per effective square inch of sectional area.

"Surveyors will remember that the strength of a sphere to resist internal pressure is double that of a cylinder of the same diameter and thickness.

"All manholes and openings must be stiffened with compensating-rings of at least the same effective sectional area as the plates cut out, and in no case should the plate-rings

* If the rivets are exposed to double-shear multiply the percentage as found by 1.5.

be less in thickness than the plates to which they are attached. The openings in the shells of cylindrical boilers should have their shorter axes placed longitudinally. It is very desirable that the compensating-rings round openings in flat surfaces be made of L or T iron."

4. Furnaces.—The plates used in the construction of the furnaces should be made as thin as is consistent with proper strength and stiffness, because thick plates are liable to blister when exposed to the intense heat of the fire. For the same reason as few seams as possible are used in the furnace and back-connection, and the lap-joints are single-riveted. The laps should be placed in such a direction that the current of the products of combustion does not strike the edge of the plate, and that there is no tendency for the scale to lodge and accumulate at any place exposed to an intense heat. The furnace-crown should have as little bracing as practicable, and the attachments of the stays and braces should be of such a form that they interfere as little as possible with the circulation of the water, and do not serve as a nucleus for an excessive accumulation of scale.

For furnaces special brands of iron, known as "*fire-box*" and "*extra fire-box*" iron, are used, which are specially fitted to withstand the oxidizing and wasting influence of intense heat and the impact of flame. The furnaces of all boilers built for the English Admiralty are made of "*Low Moor*" or "*Bowling*" iron. It is essential that the iron used for furnaces should be free from all lamination. The use of mild steel for furnaces is advantageous especially on account of its homogeneous structure; it is, however, necessary to exercise great care in the selection and use of steel for furnaces, since in many instances the steel plates of furnaces and fire-boxes have cracked after having been in use a short time, although the material was of a mild quality and stood the tempering-test well.

Copper has been used extensively for locomotive fire-boxes, especially in Europe, on account of its homogeneous structure and high thermal conductivity, but it is not used for marine boilers.

Various devices have been proposed for increasing the heating-surface of the furnace, but nearly all of them interfere to so great an extent with the removal of the scale or with the cleaning of the fire, besides presenting difficulties of construction, that they are almost unknown in practice.

The corrugated boiler-flues made by the *Leeds Forge Company* (England), under the patents of S. Fox, have come into extensive use of late, and have generally given satisfaction. In some cases iron corrugated furnace-flues have shown signs of blistering after having been in use a short time; but this is ascribed to original defects in the

plates, and not to any injurious effect of the process of manufacture. Corrugated flues have borne test-pressures more than twice as great as the pressures at which plain cylindrical flues, made of the same material and of equal dimensions, collapsed. The great resistance to collapse of corrugated flues of an oval cross-section, compared with that of plain oval flues, is of special importance. These corrugated flues possess great longitudinal elasticity, and thus accommodate themselves readily to differences of pressure and temperature, rendering the flat plates of the boiler-front and back-connection to which they are fastened less liable to grooving. This longitudinal elasticity prevents thick scale from adhering firmly to the metal, and thus the surfaces of the tubes are always kept clean; by this fact the greater evaporative efficiency claimed for corrugated boiler-flues may perhaps be explained.

These flues are made either of the best Yorkshire iron or of Siemens-Martin steel of a very mild quality. The plate is first bent to a cylinder and welded by machinery; then the circumferential corrugations are rolled in. It is proposed to roll solid steel tubes without welds from seamless circular blooms under S. Fox's patents.

The following data in reference to tests of S. Fox's corrugated boiler-flues are given in *Engineering*, March, 1878, and June, 1880:

A flue made of welded steel, $\frac{3}{8}$ inch thick, had thirteen corrugations in a length of 6 feet $\frac{1}{4}$ inch between extreme centres, giving a mean pitch of 6.03 inches. The depth of the corrugations was $1\frac{1}{2}$ inches, and the mean least diameter of the flue was about $33\frac{1}{2}$ inches. There was at each end a plain part extending $12\frac{1}{2}$ inches beyond the end corrugations; these plain parts were packed in the end plates of the test-cylinder by cupped leather rings. In this manner the flue was quite free to move longitudinally.

The flue bore a hydraulic pressure of 550 lbs. per square inch without showing any permanent set. At a pressure of 600 lbs. the flue began to fail, but retained a symmetrical oval form, the difference of the longer and shorter diameters being about 5 inches. This oval flue, being again tested, gave way at a pressure of 350 lbs.

A welded iron flue, $\frac{3}{8}$ inch thick, having a mean least diameter of about $35\frac{1}{2}$ inches, and having circumferential corrugations $1\frac{5}{16}$ inches deep and 6 inches pitch, was tested in the same apparatus, and gave way by general distortion as a pressure of 450 lbs. was approached.

A plain cylindrical flue, made of the same material, $\frac{3}{8}$ inch thick, and having a mean horizontal diameter of 36.63 inches and a mean vertical diameter of 36.98 inches, came down like a blister on the top at a pressure of 200 lbs. while being tested in the same apparatus.

Corrugated plates are also coming into use for the fire-boxes of portable and locomo-

tive boilers in England. In *Garret's* portable engine boilers the top of the rectangular fire-box is made with several deep corrugations extending lengthwise the furnace. The *Leeds Forge Company* are building portable and locomotive boilers the semi-cylindrical top and flat sides of which are stayed by a new system of diagonal corrugations patented by Fox and Greig. The external shell around the fire-box is corrugated in the same manner, and the use of stay-bolts and sling-stays is dispensed with.

5. Furnaces of Rectangular Boilers.—Furnaces of rectangular or semi-cylindrical boilers have generally flat, vertical sides joined to a flat bottom by corners curved to a short radius, and to a more or less arched crown.

Fig. 93.

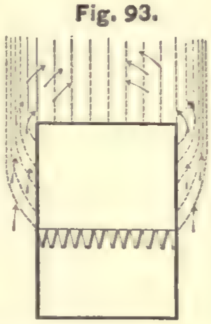
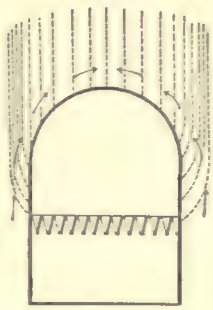


Fig. 94.



A flat furnace-crown is not only the weakest form, requiring very heavy bracing, but interferes greatly with the proper circulation of the water. Figures 93, 94 are intended to illustrate the circulation of the water with flat and arched furnace-crowns respectively, the dotted lines representing the ascending bubbles of steam, and the arrows indicating the direction of the currents of water flowing in to fill the vacant space. Flat furnace-crowns have the advantage of making the furnaces roomy over the grate, and are used generally in locomotives, in which heavier bracing can be used with safety on the furnace-crown than in marine boilers, since they are less liable to be injured by incrustations. In marine boilers, carrying a moderate steam-pressure, the furnace-crown has often the form of a flat arch; in this case the crown-sheet is lap-jointed to the flat sides; sometimes the arched crown-sheet is bent to a shorter radius where it is joined to the sides, as in figure 95.

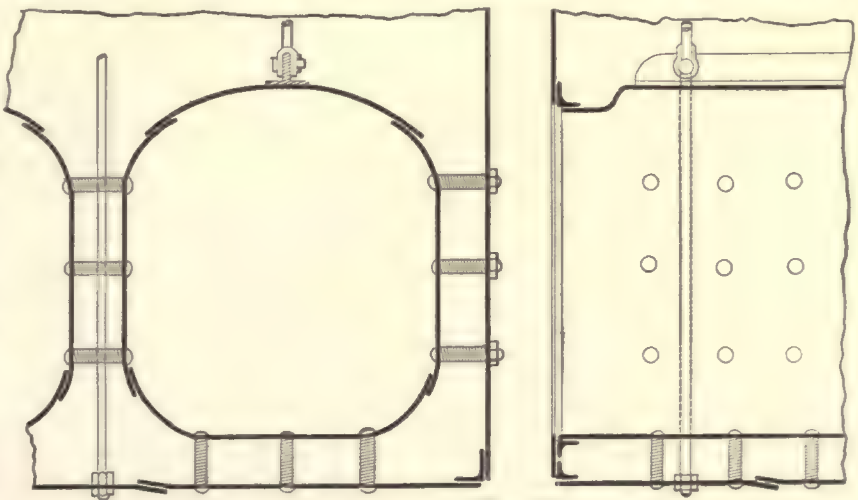


Fig. 95.

The form of furnaces commonly used in United States naval vessels is illustrated on

Plates VI., VII., XVII. The semi-cylindrical form of the furnace-crown gives a much less roomy furnace, but it makes the inside of the boiler much more accessible for the same height of boiler, and requires scarcely any bracing. In this case the whole crown and the straight sides of the furnace may be made in one piece, so that no seams occur in the furnace except at the ends and below the grate; but often the crown-sheet consists of two plates connected by a transverse seam in the middle of the furnace. When it is necessary to use longitudinal seams within the furnace above the grate they should never be placed near the line of fire, but (as in Plate XVII.) near the top of the crown, far enough to one side to clear the foot of the braces. The fibre of the plates forming the furnace runs generally circumferentially.

The flanges required to secure the furnace in the boiler at the front and back are generally not turned on the plates forming the furnace; in some English and French boilers a flange is turned outward on the back end of the furnace-crown, to a radius of four or five inches, to connect it with the back tube-sheet. With this method of fastening the movements due to the expansion and contraction of the furnace and of the tubes tend to spring the joint open and cause leaks, unless the flange is made sufficiently flexible by the large radius with which it is turned. Angle-irons are frequently used in English and French practice for securing the furnace at the front and back in the boiler. The cheapest way of securing the furnace to the front of the boiler is to cut out the front plate equal to the cross-section of the furnace, rivet an angle-iron around this opening, inside or outside the shell, and secure the furnace to this angle-iron. Cast-iron frames, to which the furnace and ashpit doors are attached, are bolted to the front of the boiler around the furnace-opening. These large frames are apt to warp and crack, and give much trouble. On this account the furnace-mouth is contracted in many French and English boilers by flanging the furnace crown-sheet downward in the manner shown in figure 95.

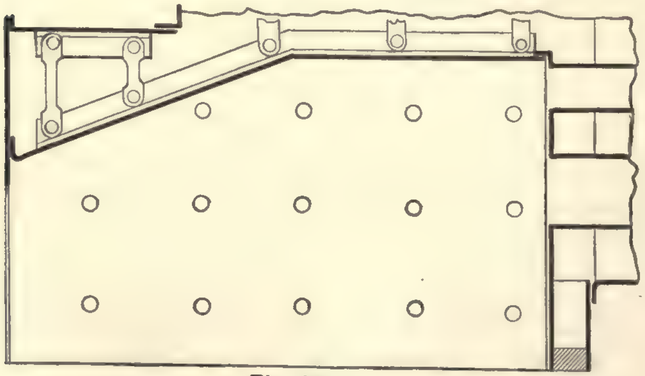


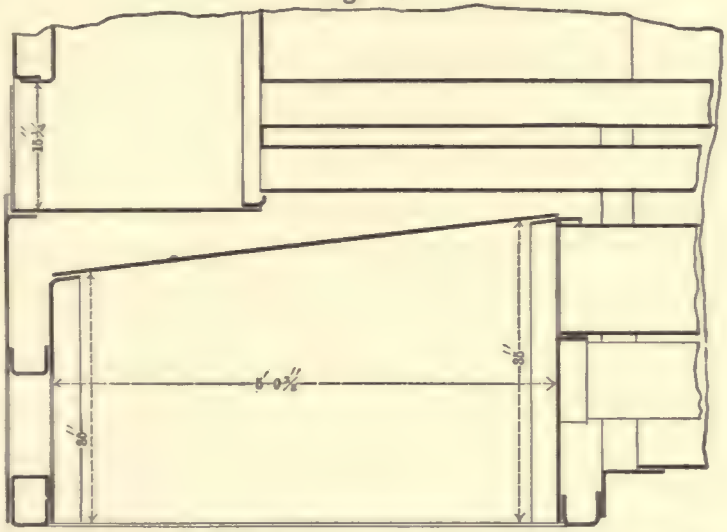
Fig. 96.

Sometimes the crown-sheet is made to slope downward to the front of the boiler, as illustrated in figures 96, 97, in order to gain room under the front-connection, when the boiler is necessarily low. This can be done without impairing the efficiency of the furnace, since more height is required over the grate at the back than at the front.

Figure 96 represents the furnace of a tubular marine boiler built by Laird & Son, Birkenhead, England; and figure 97 represents the furnace of a boiler for the United States tugboat *Glance*, built in 1879.

When the water-spaces are too narrow to connect the furnace to the shell by flanges turned on the respective plates, or by special flanged pieces as around the furnace-door opening in figure 97, the connection is formed either by placing a frame, formed by bending and welding a wrought-iron bar of square cross-section to the required shape, between the furnace and the shell, and riveting the plates to the frame by through-rivets (as at the bottom of the boiler in figure 96, and around the furnace door-opening in figure 1, Plate XXVIII.), or by bending the plate of the furnace with an easy, reverse curve outward, and riveting it directly to the shell (as at the bottom of the boilers represented on Plate XXVIII.).

Fig. 97.



The usual method of securing the furnace used in boilers of United States naval vessels is illustrated on Plates VI., VII., and XVII. An opening of the size and shape required for the furnace-door and ashpit is formed in the boiler-front, a flange being turned inward around this opening. The crown-sheet and sides of the furnace are riveted to a separate flanged piece, which has an opening corresponding to the furnace-door opening of the boiler-front, but is flanged outward around this opening. A narrow strip is riveted inside the furnace-door opening to the flanges of the boiler-front and of the furnace front-piece.

The bottom of the furnace of rectangular boilers is sometimes arched downward; but the flat bottom, illustrated on Plate XVII., is best adapted for supporting the flat bottom of the boiler by stay-bolts, while the curved corners give additional room in the water-space for collecting solid matter and for cleaning out the water-legs and the water-bottom through the handholes.

The principal use of the water-bottom is to form a convenient ashpan, which does

not become overheated and warped by the heat radiated through the grate and by the fire falling through the bars; it serves also as a receptacle for mud, broken scale, and other solid matter entering the boiler with the feed-water. The water-bottom is generally one of the first parts to give out in marine boilers through internal and external corrosion, and it is in many cases inaccessible for thorough repair while the boilers remain in the vessel. On this account they are often omitted, and separate cast-iron or wrought-iron ashpans are placed under each furnace. The weight of these so-called dry-bottom boilers, including the supports and ashpans, is about the same as that of the water-bottom boilers, including the additional amount of water carried by them; but the former are somewhat cheaper to construct. To prevent the over-heating and warping of the ashpans of dry-bottom boilers water has to be kept in them. Although they deteriorate rapidly, the durability of the boiler is not impaired thereby as by the corrosion of the water-bottoms. The durability of the latter is increased by giving to the plates an additional thickness in order to allow for corrosion.

To form the water-legs of the dry-bottom boiler the sides of the furnaces, carried some distance below the grates, are connected at the bottom by a separate curved plate. The lap of this plate is often placed inside the boiler; by placing it on the outside the joint is made more accessible for calking while the boiler remains in position in the ship, and some additional room is gained in the water-leg. Sometimes the water-legs are enlarged at the bottom to make them more accessible for cleaning; they must extend far enough below the grate so that there is no danger of their becoming filled with solid matter up to the line of fire. It is well to let the bottom of the water-space running lengthwise at the back of the boiler terminate in a cylindrical drum, unobstructed by stays and accessible through manholes placed at the ends for cleaning and repairs (see figure 98).

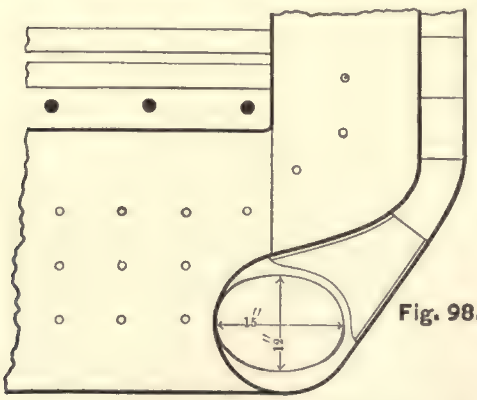


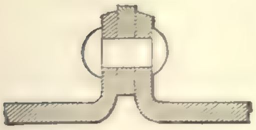
Fig. 98.

6. Cylindrical Furnaces.—The furnaces of cylindrical boilers calculated to carry steam of a high pressure are made of a circular cross-section. In chapter vi. the laws governing the collapsing strength of cylindrical flues have been investigated, and the importance of making their cross-section perfectly circular has been pointed out. For this reason the furnace-flues are generally made with longitudinal butt-joints, and not with lap-joints. The strap is placed inside the flue at the side and below the grate, so as to be accessible for calking, not to come in contact with the

fire, and not to be in the way of hauling the ashes. It is still better to weld the longitudinal seams in the manner described in section 20, chapter viii.

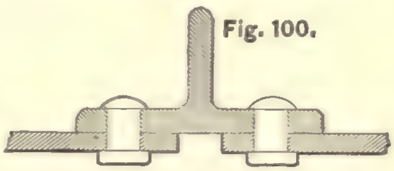
The necessity of stiffening long flues by flanges or by riveting bands around them at intervals has been demonstrated in chapter vi. In boilers of United States naval vessels the furnace-flues are generally strengthened by means of the "*Adamson*" joint (see figure 99 and Plates VIII., XI., XII.) The furnace-flue consists of two or three sections flanged outward; a wrought-iron ring, about $\frac{5}{8}''$ thick, is placed between the flanges, and the sections are connected by single-riveting. There are no laps or rivets in contact with the fire, and the ring or welt allows the joint to be calked from the inside and outside. This flanging can be done only with very good iron; in some boiler-works it is done by machinery in one or two heats, which distresses the plate less than the repeated heating with the common method—an important advantage, especially in the case of steel. The radius at the root of the flange should not be less than $\frac{5}{8}$ inch on the inside, or the plate will be liable to become grooved by the alternate expansion and contraction.

Fig. 99.



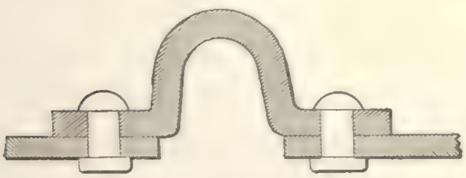
Sometimes the several lengths of the furnace-flue are connected by T-iron rings, as shown in figure 100. In order to admit of calking these joints at any time from inside the furnace a clear space of at least one inch should always be allowed between the ends of the plates; this lessens also the liability to overheating at the seam. Accurate workmanship is required for this joint; the two lengths of tube embraced by the same ring must be of exactly the same diameter or the joint will give trouble.

Fig. 100.



In order to allow for the contraction and expansion of the furnace-flue, which often cause serious trouble by grooving in long boilers, the *Bowling hoop* has been introduced (see figure 101). Like the T-iron hoop, it has the disadvantage of placing a double thickness of plate and the rivet-heads in the fire at the joints.

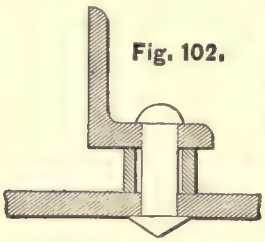
Fig. 101.



The report of the Chief-Engineer of the Manchester Steam-Users' Association for the year 1871 contains the following directions regarding the application of strengthening-hoops to the flues of boilers originally made without them:

"The hoops should be of angle-iron section, about $3'' \times 3'' \times \frac{1}{2}''$. They should be made in halves, so that they may be passed in at the manhole and then riveted to the

furnace or flue tubes in position, thus rendering it unnecessary either to remove the tubes or cut any opening in the boiler. The angle-iron should not be brought into direct contact with the plates of the tube, but a clear space of not less than one inch should be left between the two, the hoop for this purpose having a diameter some two inches larger than the furnace-tube (see figure 102). The hoop should be secured to the furnace-tube by rivets spaced about six inches apart; blocking-pieces, through which the rivets should pass, being inserted between the tube and the angle-iron, so as to give a solid abutment for the riveting, while the halves of the hoop should be connected by butt-straps riveted to their ends at the back. . . . The blocking-pieces should be made of a strip of iron not more than $\frac{3}{16}$ inch thick, bent round into a circular shape, the ends being welded together so as to form a short tube or ferrule. These ferrules should be well fitted into the space between the hoop and the plating of the furnace and flue tube, while the ends of one half-hoop should be firmly butted against the ends of the other half-hoop, so that the whole may be tightly drawn together, as much of the support afforded by these hoops depends on their being made one with the furnace and flue tubes, and not put in so as to act merely as separate hoops from which the plates are hung. . . .



"A hoop of angle-iron is preferable to one of T-iron, as the single flange of the angle-iron, being narrower than the double flange of the T-iron, offers less impediment to the escape of the steam generated within the annular space, and also less harborage for deposit. . . . The hoops should not be allowed to touch the shell of the boiler, or the furnace-tubes may become strained and leakage be induced, since furnace and flue tubes rise and fall with variations of temperature, and thus grind against the sides of the shell or against one another where in contact."

Hoops secured in the foregoing manner should be used only when their addition is an after-consideration; for new structures one of the joints illustrated in figures 99, 100, and 101 should be used, because, as has been pointed out in section 3, chapter vi., it is important that the flanges or rings supporting a flue should be attached to it rigidly around its whole circumference, and not merely connected with it at detached points. When a boiler contains several furnaces it is well to arrange the lengths of the sections forming the flues in such a manner that the flanges or strengthening-hoops of adjoining furnaces are about six inches apart, so that any loose scale dropping down from above does not lodge between the flanges.

Angle-iron rings are frequently used in French and English boilers for securing the furnaces to the shell and to the back-connections. In all cylindrical boilers constructed

for United States naval vessels the furnaces are riveted to flanges turned on the back tube-sheet and on the front-head of the boiler, double-riveting being used at the front and single-riveting at the back of the furnace.

The furnaces of the boiler illustrated on Plate XV. are made of two plates, the upper one $\frac{1}{2}''$ thick and the bottom one $\frac{9}{16}''$ thick, welded together 6 inches below the centre line. The plate forming the furnace-crown is flanged outward at the back and is riveted to the back tube-sheet; the bottom-plate is continued straight till it meets the back-plate of the back-connection, being riveted to the flange turned on the latter.

Lloyd's formula for the collapsing strength of circular flues is:

$$\frac{89{,}600 \times \text{square of thickness of plate in inches}}{\text{Length of flue in feet} \times \text{outside diameter of flue in inches}} = \begin{cases}\text{working pressure in} \\ \text{pounds per sq. inch.}\end{cases}$$

The Surveyors of the Board of Trade (England) determine the strength of circular furnaces according to the following rule:

"Circular furnaces with the longitudinal joints welded or made with a butt-strap:

$$\frac{90{,}000 \times \text{the square of the thickness of the plate in inches}}{(\text{Length in feet} + 1) \times \text{diameter in inches}} = \text{working pressure per sq. in.}$$

"Without the Board's special approval of the plans the pressure is in no case to exceed $\frac{8{,}000 \times \text{thickness in inches}}{\text{diameter in inches}}$. The length to be measured between the rings, if the furnace is made with rings.

"If the longitudinal joints, instead of being butted, are lap-jointed in the ordinary way, then 70,000 is to be used instead of 90,000, excepting only when the lap is bevelled and so made as to give the flues the form of a *true* circle, when 80,000 may be used.

"When the material or the workmanship is not of the best quality the constants given above must be reduced—that is to say, the 90,000 will become 80,000, the 80,000 will become 70,000, the 70,000 will become 60,000; and when neither the material nor the workmanship is of the best quality such constants will require to be further reduced, according to circumstances and the judgment of the surveyor, as in the case of old boilers.

"One of the conditions of best workmanship must be that the joints are either double-riveted with single butt-straps or single-riveted with double butt-straps, and the holes drilled after the bending is done and when in place, and afterwards taken apart, the burr on the holes taken off, and the holes slightly countersunk from the outside."

7. Combustion-chambers and Back-connections.—In the usual type of loco-

motive boilers (see Plates IV. and V.) the front tube-sheet forms the back of the furnace ; in other instances (see Plate III.) the gases enter a separate combustion-chamber on leaving the furnace ; and in the usual type of return-tube boilers the back-connection serves as a combustion-chamber.

The opening leading from the furnace to the combustion-chamber is contracted to the smallest area that will give the required draught by the bridge which at the same time serves as a support for the back of the grate. Plates VI., VII., XVII. illustrate the usual manner of forming the bridge-wall in rectangular boilers of United States naval vessels. In cylindrical marine boilers, where the simplest forms and unstayed surfaces are used as much as possible, the bridge is generally formed by a casting lined with fire-brick above the surface of the grate. Figure 1, Plate III., illustrates a frequent mode of forming the bridge—viz., by means of a hollow wall communicating with the water-space of the boiler ; this is called a *water-bridge.* The top of a water-bridge should always slope or curve upwards towards the ends to admit of the rapid escape of steam-bubbles. Sometimes a water-bridge projects downward for the purpose of deflecting the flame ; it is then called a *hanging-bridge.*

Return-tubular boilers are built either with one back-connection common to all the furnaces or with a separate back-connection for each furnace. The former plan simplifies the construction and lessens greatly the weight of the boiler, including water ; and since it admits of placing at least one additional row of tubes over each furnace, the heating-surface is about the same as when each furnace has a separate back-connection. The principal advantages of the latter plan are twofold—viz., *first*, the products of combustion are kept separate till they enter the front-connection or uptake, consequently the efficiency of any furnace is not affected by counter-currents, or currents of cold air entering the back-connection through adjoining furnaces ; *secondly*, the water-spaces between the separate back-connections and nests of tubes are of great utility in facilitating the circulation of the water in the boiler. When more than two furnaces are contained in the same shell separate back-connections are generally used. Cylindrical boilers calculated to bear a high pressure of steam are often made with one common back-connection, in order to reduce the amount of flat stayed surface as much as possible ; when they contain more than two furnaces it would be difficult to get plates of sufficient size for a single back tube-sheet and to flange the sheet properly.

In the horizontal-tubular boiler the front of the back-connection is formed by the back tube-sheet, which in the cylindrical boiler consists of one plate. In the rectangular boiler it generally extends down to the straight sides of the furnace. A flange

encircling the furnace is turned on the tube-sheet; the top and sides of the same are likewise flanged for riveting it to the top and side plates of the back-connection.

In the vertical return-tube boiler the bottom tube-sheet is connected with the furnace by a separate flanged piece (see Plates VI., VII.) The top of the back-connection is often formed by curving the back-plate to a large radius; in other cases the back-plate is made to slope inward, thereby increasing the width of the water-space at the back of the boiler, and allowing the steam-bubbles to escape from the plate readily as soon as formed. It is necessary to leave sufficient room at the top of the back-connection for calking the seams and expanding the tubes.

8. Systems of Boiler-building.—The preliminary tests applied to boiler-plates to determine their strength, soundness, and quality, methods of developing the lines of curved sheets and laying out the flanges and rivet-holes, and the various operations of bending, flanging, welding, shearing, punching, drilling, riveting, and calking, have been described and discussed in chapters v. and viii.

Various systems are followed by boiler-makers in building boilers, as far as the laying-off, the fitting, and the order in which the several parts are riveted together are concerned. Since in bending, flanging, and forming the plates absolute accuracy in accordance with prescribed dimensions is impracticable, and since slight changes in the location of laps and seams often encroach upon the available space in such a manner as to make other modifications absolutely necessary, it is important to verify all work by fitting the plates together after they are bent and flanged, securing them temporarily by bolts, placing the various parts of the boiler in position, and thus to make sure before riveting the joints permanently that this can be done without straining any part unduly, and that the proper clearance is maintained between the several parts. Care must be had to join the parts together in such order as to have all seams accessible for riveting and calking.

The rivet-holes in the shell of rectangular boilers are generally punched or drilled at first in one plate only, which then serves as a template for marking the corresponding holes on the other plate while it is temporarily fitted and secured in position. The rivet-holes of the circumferential and longitudinal seams of cylindrical shells and of their butt-straps are often all laid off and punched or drilled before the plates are bent; this work can be done more accurately, however, when the holes of each seam are formed in one plate only, which then serves as a template for drilling the corresponding holes in the other plates while secured in position, as described in section 6 of chapter viii.

In building the boiler represented on Plate XII. the two rings forming the cylindri-

cal shell are fitted and secured together with their butt-straps by tack-bolts. The back-head, having been flanged in the meanwhile, is then fitted in place, and the rivet-holes on the circumferential flange are marked and drilled. The back-head having been fitted and secured again to the back-section of the shell, the longitudinal butt-strap of the latter and the transverse seam of the back-head are riveted, and the back-head is riveted to the shell. The circumferential butt-strap is riveted to the back-section, while the front-section is fitted and secured to it; the longitudinal and circumferential seams of the front-section are then likewise riveted. After this the laps are calked from the inside, and the gusset and stay plates are fitted and bolted to the back-head. In the meanwhile the furnace-flues have been constructed, the different sections having been riveted together and calked; the front and back tube-sheets have been flanged and drilled, and are being fitted to the furnace-flues. In doing this the tube-sheets are kept the proper distance apart and parallel with each other by a couple of wooden struts and some long bolts passing through the tube-holes; a few tubes are put through the holes to make sure that the corresponding holes in the two plates come fair with each other; thus secured, the furnaces and tube-sheets are fitted in the boiler-shell. The holes in the flanges joining the tube-sheets to the furnaces and the front-head to the shell are marked and drilled. The furnaces having been removed from the shell, they are riveted to the back tube-sheet, and the flanges encircling the furnaces are calked. The plates forming the back-connection are fitted to the back tube-sheet, and the furnaces and back-connection, temporarily connected by bolts, are fitted in the shell. The rivet-holes of the seams of the back-connection are then marked and drilled, the plates are riveted in place, and such joints as would not be accessible afterward are calked as soon as riveted. The furnaces and back-connections are now placed in position in the shell; the front-head is fitted and riveted to the furnaces and to the shell; the stay and gusset plates are riveted to the heads and back-connections; the stay-bolts and other braces are put in place and secured. The tubes are then put in and expanded, and finally all remaining seams are calked.

In building rectangular boilers the bottom and the lower part of the sides and back are fitted and riveted while the furnaces and back-connections are being constructed; these are then put in position in the shell on blocks or wedges; the front, as far as the front-connection, is fitted and riveted, the holes for stays are marked and drilled, and the furnaces are permanently secured within the shell by stay-bolts, and the crow-feet for the attachment of the braces are riveted to the furnace-crowns. The plates forming the back, sides, and top are in the meanwhile fitted and riveted on, generally one sheet at a time.

The tube-boxes of the vertical-tubular boiler represented on Plates VI. and VII. are fitted, riveted, and calked; the lugs and straps for the attachment of the braces are riveted to them, and, when the sides of adjoining boxes are tied together by lugs and pins instead of stay-rivets, the tubes are put in and expanded before the boxes are put into the boiler.

The front-connection and uptake are then built in, and, before the boiler is finally closed, the angle-irons and long braces, dry-pipes, surface blow-pipes, and everything which could not afterwards be introduced through manholes are passed into the boiler. The braces having been connected, the tubes are put in and expanded, and all the remaining seams of the boiler are calked inside and outside.

CHAPTER X.

STAYS AND BRACES.

1. Systems of Bracing.—Bracing has to be applied to all surfaces of a boiler which are liable to alteration of form under pressure. The only figures which require no bracing when subjected to an internal pressure are the cylinder and the sphere. Mathematical formulæ expressing the resistance of cylindrical and spherical forms to a bursting pressure have been developed in sections 1 and 2, chapter vi.; and in section 3 of the same chapter the resistance of cylindrical flues to an external collapsing pressure has been investigated.

Surfaces are stayed, *first*, by contrivances which make them self-supporting, or transmit the strain due to the pressure on them to well-supported places lying in the same plane. To this class belong the girder-stays used on locomotive fire-boxes and on the flat top of the back-connections of many marine boilers (see Plates IV., V., XV.); the angle-irons, T-irons, and spherical strengthening-domes sometimes used on flat surfaces of small extent (see Plate XII.); likewise the various devices for strengthening furnace-flues described in section 6 of chapter ix.

Secondly, by tying them to other surfaces lying in different planes and experiencing an equal amount and kind of stress in an opposite direction, or possessing sufficient stiffness to prevent alteration of form. The latter method is the one most usually employed; stay-bolts, rod-braces, direct or oblique, branch-braces, stay-tubes, and gusset-plates are used for this purpose. These two methods are also frequently used in combination, as when angle or T-irons or stay-plates are used to distribute the strain of braces over a larger area of the stayed surface.

There are several advantages in favor of diminishing the number of braces and increasing their sectional area correspondingly—viz., the boiler is made more accessible and the circulation of the water is less obstructed; it is easier to give an equal tension to the fewer braces; larger braces are relatively less reduced in sectional area by an equal rate of corrosion than smaller ones. When, however, the spacing of the braces exceeds a certain limit, depending on the steam-pressure and the thickness of the plate, the latter bulges excessively between the stays, and, even if rupture does not take place,

leaks occur around the stays; to prevent this action the plates have to be stiffened in such cases by T or angle irons or by an additional thickness of plate.

Various devices in bracing are employed to keep the interior of the boiler accessible as much as possible: the braces are made so that they can be easily removed and replaced; they are spaced as wide apart as practicable; surfaces are strengthened by self-supporting devices, or diagonal braces and gusset-plates are used to tie adjoining sides together, leaving the space midway between the ends of the boiler unobstructed. In order to obstruct the interior of the boiler as little as possible without leaving too long an interval between the attachment of the braces, two or more short oblique braces are attached to one main-brace; the connection of these branches with one another and with the main-brace is made either by a flexible joint or by welding. These branch-braces are also called "*half-moon*" braces from the form sometimes given to the branches.

Careful attention must be paid to see that the parts to which the braces supporting a surface are attached are strong enough and sufficiently stayed to bear the strain thrown on them. Difficulties may be encountered in this respect when a larger surface is tied to a smaller one. When a surface is tied to a self-supporting cylindrical surface the strain on the latter will no longer be uniformly distributed around its circumference, and distortion will take place unless the cylindrical plate possesses a surplus of stiffness.

In cylindrical marine boilers the cylindrical shell is self-supporting; the flat ends and the back-connections have to be supported by bracing; the methods used to secure flues against collapse have been described in the last chapter. Above the back-connections the flat ends are either tied directly together by braces extending through the whole length of the boiler, or are secured to the adjoining portions of the shell by oblique braces or gusset-plates. The lower parts of the flat ends are tied to the back-connections. The back-head is secured to the latter by stay-bolts; the tube-sheets are held by the tubes, and for further security special stay-tubes or rod-braces are often added. The furnace-flues serve to tie the lower part of the front-head to the back-connection, and any portions of these parts remaining unsupported are either tied together by rod-braces or are strengthened by gussets, angle-irons, stay-domes, or similar devices. The sides and bottom of the back-connections are secured against collapse by tying them with stay-bolts to the circular shell or to opposite flat sides. The top of the back-connections is generally supported either by girder-stays or by gusset-plates secured to the back-head.

Plates XVII., XVIII. illustrate the system of bracing used in rectangular boilers of United States naval vessels. These boilers are designed to carry from 35 to 40 pounds

of steam, and the shell is made of $\frac{5}{16}$-inch or $\frac{3}{8}$-inch iron. Opposite portions of the flat bottom and sides of the furnaces and connections and of the lower part of the shell are tied to one another by socket-bolts spaced from $7\frac{1}{2}$ to 9 inches apart. The tube-sheets are sufficiently stayed by the tubes. The upper portions of the ends and of the back and front of the shell are tied together by a system of parallel horizontal branch-braces traversing the length and breadth of the boiler. In the horizontal return-tube boiler the top of the shell is tied directly to the arched furnace-crown, the braces passing between the nests of tubes; but in the boiler having vertical tubes the braces of the top are attached to the sides of the tube-boxes, and these are tied to the furnace-crowns. The tendency of these braces to distort the circular furnace-crown is counteracted by a system of horizontal stays, secured near the point of attachment of the braces to opposite portions of each pair of adjacent furnaces. The braces are connected with the shell of the boiler by means of T-irons, generally $4'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$, spaced from 12 to 14 inches apart from centre to centre, and securely riveted to the shell. These T-irons run in continuous lengths as far down the sides of the boiler as is

Fig. 103.

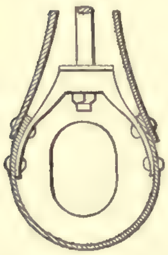


Fig. 104.

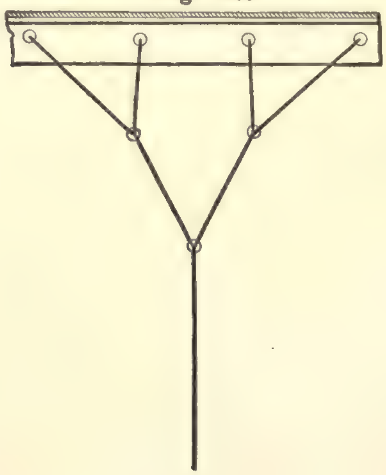
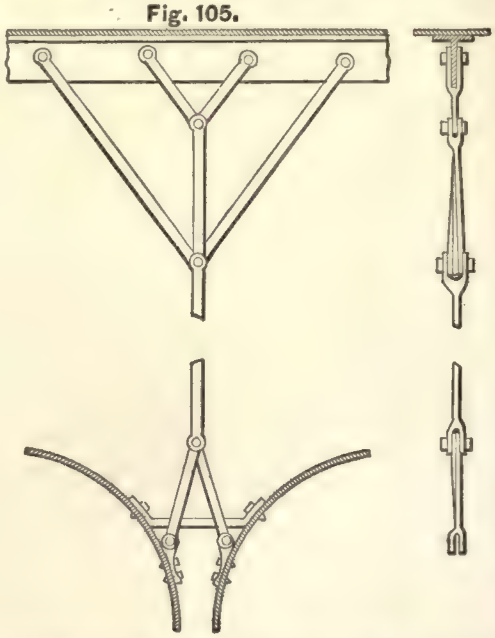


Fig. 105.



necessary for the attachment of the braces. Lugs, called "*crow-feet*," are riveted to the furnace-crowns and to the top of the back-connections for the attachment of the braces by means of a bolt passing through the eye (see Plate XVIII.) Similar lugs are riveted

to the top and bottom of the sides of the vertical tube-boxes of the boiler illustrated on Plate VI.

In many English horizontal return-tube boilers the lower ends of the braces supporting the flat top are attached in the manner shown in figure 95. By the direct attachment of the braces to the bottom of the boiler the arched furnace-crown is kept free from unnecessary bracing; but the cleaning of the boiler through the handholes is rendered difficult. This defect is remedied by attaching these braces in the manner shown in figure 103, a method used principally in dry-bottom boilers.

In order to dispense with the braces which are attached to the centre of the furnace-crown it has been proposed to subdivide each branch of the braces supporting the top of rectangular boilers in the manner shown in figure 104; and in the horizontal return-tube boilers of the U. S. S. *Tippecanoe* (built in the year 1864) the system of bracing shown in figure 105 was applied. The main-brace passes between the nests of tubes and is tied to the sides of the furnaces. But ordinarily it will not be found advantageous to complicate the construction of the braces by such devices, since very accurate fitting is required in order to ensure equal tension on all the branches.

Fig. 106.

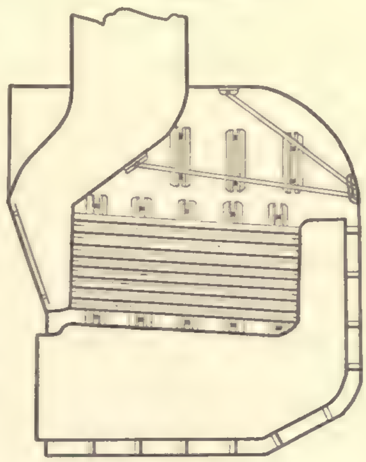


Figure 106 shows a system of bracing applied to rectangular boilers of French naval vessels. The top of the shell is tied by oblique braces to the back and front of the shell and to the uptake. No braces are attached to the arched furnace-crowns, and few braces have to be removed to make the upper part of the boiler quite accessible; but the greatly-inclined oblique braces and their attachments experience a great strain, and the top and sides of the boiler would possess much greater stiffness if the angle-irons were made in continuous lengths.

2. Rules for Proportioning Braces.—In calculating the strength of braces it is generally assumed, when the plates are thin relatively to the pressure of steam carried in the boiler, that each brace has to bear the whole strain due to the total pressure on the portion of the surface which it supports. When the thickness of the plate is increased, or when the plate is otherwise stiffened, the resistance which it offers to bending may be taken into account in proportioning the dimensions of the braces.

When the braces are spaced evenly in parallel and perpendicular rows the portion

of surface supported by each brace is represented by the rectangles into which the whole surface is divided by the rows of braces.

A large factor of safety, ranging from eight to sixteen, is used in calculating the strength of braces on account of the constant diminution of their sectional area by corrosion, the uncertain strength of welded parts, and the impossibility of ensuring an equal tension on all braces under the varying conditions of pressure and temperature.

The corrosion of braces takes place most rapidly at or near the water-level, where the mechanical action of the water in washing from side to side, and the alternate wetting and drying of the braces, cause the layers of oxide and scale to fall off, thus exposing new surfaces to corrosion. The stay-bolts of water-bottoms corrode rapidly because dirt accumulates there, which absorbs and retains moisture and often contains corrosive substances. It is also found that braces in the path of steam flowing to stop-valves, etc., suffer greatly from decay, and that braces are more easily attacked at welds than at points where the fibres of the rolled bar have remained undisturbed. It is recommended to protect braces by thin washes of Portland cement, or by wrapping them with marline or canvas and white or red lead, and with galvanized iron wire. Rods of circular section are evidently less affected by corrosion than square or flat bars and gusset or stay plates, since they expose less surface in proportion to their sectional area.

'Lloyd's Register of British and Foreign Shipping' contains the following "Rules for Determining the Working Pressure in New Boilers":

"*Stays.*—The stays supporting the flat surfaces are not to be subjected to a greater strain than 6,000 lbs. per square inch of section if of iron, and 8,000 lbs. if of steel, calculated from the weakest part of the stay or fastening, and no steel stays are to be welded.

"*Flat Plates.*—The strength of flat plates supported by stays to be taken from the following formula:

$$\frac{C \times T^2}{P^2} = \textit{working pressure in lbs. per square inch,} \qquad \text{[I.]}$$

where $T =$ thickness of plate in sixteenths of an inch;

$P =$ greatest pitch in inches;

$C = 90$ for plates $\frac{7}{16}$ thick and below, fitted with screw-stays with riveted heads;

$C = 100$ for plates above $\frac{7}{16}$, fitted with screw-stays with riveted heads;

$C = 110$ for plates $\frac{7}{16}$ thick and under, fitted with screw-stays and nuts;

$C = 120$ for plates above $\frac{7}{16}$, fitted with screw-stays and nuts;

$C = 140$ for plates fitted with stays with double nuts;

$C = 160$ for plates fitted with stays with double nuts, and washers, at least $\frac{1}{2}$ thickness of plates and a diameter of $\frac{2}{3}$ of the pitch, riveted to the plates.

"NOTE.—In the case of front-plates of boilers in the steam-space these numbers should be reduced 20 per cent., unless the plates are guarded from the direct action of the heat."

The rules of the Board of Trade (English) limit to 5,000 lbs. the pressure per effective square inch of area of stay, but allow a greater pressure when the flat surface is stiffened by T-irons or angle-irons in an approved manner.

The same authority prescribes the following rules for determining the highest admissible steam-pressure in boilers under their supervision, according to the manner in which the stays are spaced and secured, viz.:

"The pressure on plates forming flat surfaces will be easily found by the following formula, which is used in the Board of Trade:

$$\frac{C \times (T+1)^2}{S-6} = \text{working pressure.} \quad [\text{II.}]$$

T = thickness of plate in sixteenths of an inch;

S = surface supported in square inches;

C = constant according to the following circumstances:

$C = 100$ when the plates are not exposed to the impact of heat or flame, and the stays are fitted with nuts and washers, the latter being at least three times the diameter of the stay and two-thirds the thickness of the plates they cover;

$C = 90$ when the plates are not exposed to the impact of heat or flame, and the stays are fitted with nuts only;

$C = 60$ when the plates are exposed to the impact of heat or flame, and steam in contact with the plates, and the stays fitted with nuts and washers, the latter being at least three times the diameter of the stay and two-thirds the thickness of the plate they cover;

$C = 54$ when the plates are exposed to the impact of heat or flame, and steam in contact with the plate, and the stays fitted with nuts only;

$C = 80$ when the plates are exposed to the impact of heat or flame, with water in contact with the plates and the stays screwed into the plate and fitted with nuts;

$C = 60$ when the plates are exposed to the impact of heat or flame, with water in contact with the plate, and the stays screwed into the plate, having the ends riveted over to form a substantial head;

$C = 36$ when the plates are exposed to the impact of heat or flame, and steam in contact with the plates, with the stays screwed into the plate and having the ends riveted over to form a substantial head.

"When the riveted ends of screwed stays are much worn, or when the nuts are burned, the constants should be reduced; but the surveyor must act according to the circumstances that present themselves at the time of survey, and it is expected that in cases where the riveted ends of screwed stays in the combustion-boxes and furnaces are found in this state it will be often necessary to reduce the constant 60 to about 36."

The foregoing rules of Lloyd's and of the Board of Trade are modifications of formula [IX.], section 5, chapter vi., representing the strength of flat square plates secured at the edges, viz.:

$$t = \frac{n}{2}\sqrt{\frac{p}{k}} \text{ or } p = \frac{4\,t^2\,k}{n^2}.$$

In using this formula for calculating the thickness of flat plates supported by stay-bolts Weisbach substitutes for n the diagonal of the square formed by four adjacent stay-bolts. Since this diagonal is equal to $n\sqrt{2}$ we have the equation:

$$t = \frac{n}{2}\sqrt{\frac{2\,p}{k}} = n\sqrt{\frac{p}{2\,k}} \quad \text{[III.]}$$

With the dimensions usually employed in practice plates supported by stay-bolts do not give way by rupture in the middle between the rows of stays, but by buckling and stretching, thereby breaking off the riveted heads of the stays in the first place and then pulling the stay through the enlarged hole, or by tearing through the holes. It must be remembered that when a single stay gives way the area of the unsupported surface between the adjoining stays is increased four times.

Neglecting the stiffness of the plate, the following equation must exist between the strength of the stay-bolts and that of the supported flat plate, when d is the diameter of the stay-bolt, and when the tensile strength and the factor of safety of the stay-bolts and of the plate are supposed to be the same, viz.:

$$n^2 p = 2\,k\,t^2 = .7854\,d^2\,k; \text{ hence}$$

$$d = 1.6\,t \quad \text{[IV.]}$$

In practice, to allow for corrosion and give greater holding power to the riveted heads, the diameter of stay-rivets is seldom made less than twice the thickness of the plate.

Rules for proportioning and for finding the strength of screw stay-bolts with riveted ends or nuts, as deduced from a series of experiments, will be found in section 9 of the present chapter.

The tension of *gussets* must be calculated by the same rule as that for oblique stay-bars; but a much larger factor of safety must be employed in the case of gussets, not only because they expose relatively much more surface to corrosion, but because the resultant tension of a gusset is concentrated near one edge. Rankine says: "It appears advisable that its sectional area should be three or four times that of a stay-bar for sustaining the pressure on the same area."

In the *girder-stay* the plate acts as a bottom flange to the girder and is fixed at the ends, while the bar forms the web and upper flange and is merely supported at both ends. We may consider the stay as a rectangular beam supported at both ends and loaded in the middle or at several points, according to the number of bolts supporting the plate. When loaded in the middle its strength is determined by formula

$$\frac{p S l}{4} = \frac{k b d^2}{6} \text{ [V.], where}$$

p = pressure of steam in pounds per square inch;
S = area of plate supported in square inches;
l = length of span of stay-bar in inches;
b = breadth of stay-bar in inches;
d = depth of stay-bar in inches;
k = coefficient of resistance equal to about 50,000 lbs. per square inch.

A small factor of safety, about four, may be used in calculating the dimensions of the stay-bar from the foregoing formula, on account of the strength imparted by the plate acting as the bottom flange of the girder. Calling the distance between two adjoining girders from centre to centre D, and taking four as the factor of safety, we get for the *depth of the girder-bar*, from the above formula, the expression:

$$d = \frac{l}{91}\sqrt{\frac{p D}{b}} \quad \text{[VI.]}$$

The *breadth of girder-stays* varies generally from one-third to one-fifth of the depth. In wrought-iron bars having a depth of not less than one-tenth of their length the deflection due to a load, less than that required to overcome the limit of elasticity, is

trifling. The deflection varies directly as the load and the cube of the length, and inversely as the breadth and the cube of the depth.

The Board of Trade (English) prescribes the following rule for determining the highest pressure of steam admissible in boilers having surfaces stayed by girder-stays, viz.:

"When the tops of combustion-boxes or other parts of a boiler are supported by solid rectangular girders the following formula, which is used in the Board of Trade, will be useful for finding the working pressure to be allowed on the girders, assuming that they are not subjected to a greater temperature than the ordinary heat of steam, and, in the case of combustion-chambers, that the ends are fitted to the edges of the tube-plate and the back plate of the combustion-box:

$$\frac{C \times d^2 \times T}{(W - P)\, D \times L} = \text{working pressure.} \quad [\text{VII.}]$$

W = width of combustion-box in inches;
P = pitch of supporting-bolts in inches;
D = distance between the girders from centre to centre in inches;
L = length of girder in feet;
d = depth of girder in inches;
T = thickness of girder in inches;
C = 500 when the girder is fitted with one supporting-bolt;
C = 750 when the girder is fitted with two or three supporting-bolts;
C = 850 when the girder is fitted with four supporting-bolts.

"The working pressure for the supporting-bolts, and for the plate between them, shall be determined by the rule for ordinary stays."

Lloyd's Register prescribes the same rule in a slightly different form.

The *shearing strength* of *bolts*, *pins*, *or rivets* by which braces are connected or are attached to the boiler may be considered equal to the tensile strength of the brace; for the weakening effect of welding may be considered as offsetting the excess of tensile strength over shearing strength of wrought-iron.

"To find the strength of an *easy-fitting fastening* against shearing, multiply the sectional area by the modulus of strength; then take two-thirds of the product if the fastening is rectangular in section, or three-quarters if it is circular or elliptical in section.

"For a *perfectly tight-fitting fastening* the strength is the whole product just mentioned. Many actual fastenings are intermediate between easy and perfectly tight fastenings." (*Rankine.*)

Experiments on the strength of wrought-iron bolts, when subjected to the action of single-shear and of double-shear, are recorded in section 7 of the present chapter.

In proportioning the ends of eye-bars or braces connected by pins or bolts the bearing-surface of the latter is an important element of strength. When the dimensions of the bolt are proportioned so as to make its sectional area equal to the least sectional area of the bar, but with insufficient bearing-surface, the originally round hole will become pear-shaped under an excessive strain; the iron around the hole which was subjected to compression will become thickened, and the other portions of the iron around the hole which were subjected to tension will become thinned, and fracture will ultimately commence and continue at this thin part around the eye regardless of the width of the head. Experiments by Charles Fox on the flat links of the chains of suspension-bridges lead him to the conclusion that the area of the semi-cylindrical bearing-surface should be a little more than equal to the sectional area of the smallest part of the body, and, as the iron in the head is not generally as strong as that in the body, the sum of the width of the iron on both sides of the hole should be ten per cent. greater than the width of the body.

In boiler braces this increased area of bearing-surface is often obtained by making the depth of the eye greater than the diameter or thickness of the bar.

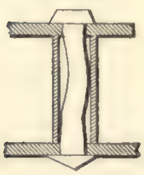
Experiments made to determine the proper proportions of pins and eye-bars, and the best method of forming them, will be found in section 8 of the present chapter.

3. Screw-stays and Socket-bolts.—In narrow spaces, as at the sides and between the furnaces and in the water-legs and water-bottoms of rectangular boilers, at the sides, back, and bottom of the back and front connections, and between the tube-boxes of vertical water-tube boilers, the opposite parallel plates are tied together by stay-bolts, of which two varieties may be distinguished—viz., screw-stays and socket-bolts. The former are screwed into both plates, and, in addition, their ends are generally secured by a riveted head or by a nut; the socket-bolts pass through the plates without being screwed, being held either by a riveted head or by a nut, and derive their name from the thimble or socket surrounding them and fitted between the plates. Such stays resist a collapsing as well as a bursting strain, and permit the riveting to be performed and the nuts to be set up hard without springing the plates. Stay-bolts should always be spaced, when possible, in vertical and horizontal rows in large surfaces, as such an arrangement facilitates the scaling of narrow water-spaces. It is necessary that the holes in the two plates connected by stay-bolts be exactly opposite each other, and that the stays stand perpendicular to both plates, else the varying lateral strains due to differences in pressure and temperature will soon cause the bolts to leak. Stay-bolts

generally fail in consequence of the excessive bulging of the plates, which causes either the heads of the stays to break or the plates to crack through the holes; the strength of such stays is therefore greatly increased by every addition to the depth of their heads and to the area covered by them. On this account stay-bolts secured by nuts are much stronger than riveted stays; and by the use of washers the strength of stayed surfaces may be still further increased. Stay-bolts secured by nuts have the additional advantage that they may be renewed in many places where rivets could not well be driven without moving the boiler from its seat. Nuts should, however, not be used on surfaces in direct contact with the fire or exposed to great heat, because they are more liable to be burnt than riveted heads, and will soon give trouble by leaking; in ashpits the nuts interfere with the hauling of the ashes and are liable to be loosened by the hoes, unless they are protected by a false ashpan.

The thimble or socket of socket-bolts (see Plate XVIII.) is either made of cast-iron or of a piece of boiler-iron bent into a cylinder. Its length should be exactly equal to the width of the space between the stayed plates. They are put in position by hand or with tongs, and are held by wooden plugs passing through them and both plates till the stay-bolts are put in. Where not otherwise accessible the sockets are *wired* into place by reeving a wire or string through both holes, hooking the bight between the plates, pulling it within reach, cutting it, passing one of the ends through the socket, fastening the cut ends together, and hauling taut on the other ends till the socket is in position. When stay-rivets are used the shank of the stay should not be too long and should fit the socket well when hot, else in riveting the shank may be bent, as represented in figure 107; in such a case, when pressure is applied, the rivet will be straightened, the plates will bulge, and leakage will ensue.

Fig. 107.



Owing to the absence of sockets screw stay-bolts are less cumbersome and obstruct narrow water-spaces less than socket-bolts, but more labor and greater accuracy in fitting are required with the former. The screw-stays should fit tight in both plates. Whenever screw stay-bolts have to be replaced it will be found necessary to ream out the holes and cut the threads anew. Hollow screw stay-bolts have been used to admit jets of air to the furnace and combustion-chamber.

For plates $\frac{3}{8}$ inch thick and less the screw-stays should have *fourteen* threads to the inch; for $\frac{1}{2}$-inch and $\frac{5}{8}$-inch plates *twelve* threads to the inch are sufficient. The thread is generally cut over the whole length of the bolt, and one end is left square till the stay is screwed into the plates. The middle of the shank should be turned down to the bottom of the thread, for it has been found that the elasticity of bars under a tensile

strain is much impaired by narrow grooves turned in them, the elongation being apparently confined to these reduced places. Bolts with a smooth shank seem also to suffer less from corrosion than when the thread is continuous.

The holding power of screw stay-bolts is greatly increased by securing their ends by nuts or by riveting them over. A very soft quality of iron is required for such stays, in order that this cold-riveting may be done without injuring the screw-threads in the plate, and that the riveted head may possess proper strength. A description of the best shape and dimensions and of the proper manner of forming the riveted heads of screw stay-bolts will be found in section 9 of the present chapter.

4. Various Forms of Stays and Modes of fastening them.—In French boilers the stay represented in figure 108 is often used in narrow water-spaces; it is stiff and efficient, preventing collapse as well as bursting, but its use involves more labor than that of stay-bolts.

The vertical sides of tube-boxes and back-connections have been stayed by means of lugs or pieces of angle-iron riveted to the opposite surfaces and connected by pins passing through corresponding holes (see figure 109). This method is to be condemned, for, even when these lugs are accurately fitted, the strain on the pin is unequal; and this action is aggravated to a dangerous extent by the almost unavoidable inaccuracies in the location of these lugs, as shown in figure 110. A less objectionable form of this

Fig. 108.

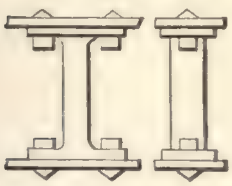


Fig. 109.

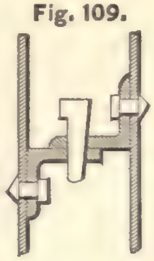


Fig. 110.

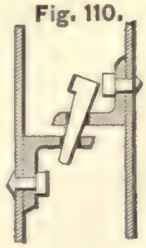
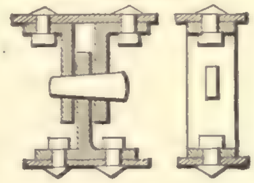


Fig. 111.



kind of stay, which was applied to the boilers of U. S. S. *Lancaster*, is shown in figure 111.

For short stays, connecting surfaces that are not parallel—for instance, on the arched crowns and at the lower rounded corners of furnaces, and on the rounded top of back-connections—a flat bar with the ends bent to the required angle, and secured at each end by a single rivet, is generally used (see Plate XVIII.) The foot should never make an acute angle with the body of this stay, else there will be difficulty in driving the rivet; on this account the two ends often have to be bent in different directions, making the stay ⅂-shaped. Such stays have the fault mentioned in connection with oblique braces

—viz., that there is a bending strain tending to spring the angle which the body of the stay forms with the foot, and which should be made, on that account, with a large fillet. When such rigidly-fastened braces are longer it is better to make the ends T-shaped, as in figure 108, and secure them by two rivets, so that there is no longer a bending strain but a direct pull on the fastenings; sometimes the ends of the brace are made forked, as in figure 112, the two branches being welded to the main body. The triangular brace shown in figure 113, used to tie the bottom of the boiler to the lower rounded corners of adjacent furnaces, is very stiff, but interferes with the cleaning of the water-bottoms through the handholes.

Fig. 112.

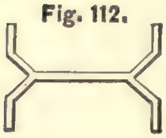
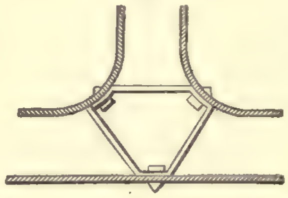


Fig. 113.



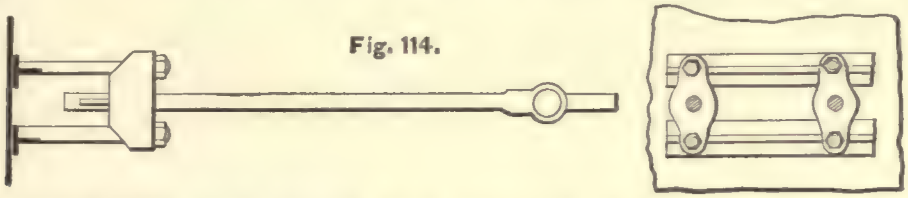
The ends of braces that have to be removed and replaced from time to time either pass through the plates and are secured by nuts and washers, or they are connected by pins or bolts with lugs, angle or T-irons riveted to the stayed surfaces inside the boiler. The former method of fastening is frequently used in English rectangular boilers for securing the lower ends of the braces which tie the top of the boiler to the bottom or to the furnace-crown and back-connection. Such braces are generally secured by a nut on both sides of the plate (see figure 95), but sometimes a shoulder forged on the brace takes the place of the nut inside the boiler. The large nuts and washers inside the furnace, exposed to an intense heat, are apt to give much trouble, and the varying lateral strains to which these long braces are exposed tend not only to cause leaks but to break off the ends in the thread. Rods secured by nuts and washers are commonly used to stay the uptake by tying it to the surrounding steam-drum.

The flat ends of cylindrical boilers are often tied together by cylindrical rods passing through the shell and secured by nuts on both sides of the plates, the ends of the brace, as far as the thread is cut, being enlarged. The strain due to the tension of these braces is distributed over the plates either by large washers or by riveting angle-irons or an extra thickness of plate to them. This brace is simple and easily adjusted, and with accurate workmanship all lateral strains may be avoided when the end plates are sufficiently stiffened so that they do not buckle to an appreciable degree. It is, however, inconvenient to remove long braces by pulling them out of the boiler, and the screw-threads inside the boiler become soon coated with rust and scale, making the turning of the nuts very difficult. On this account a different fastening was applied to some rod-braces of the boilers of U. S. S. *Terror*, illustrated on Plate IX. The brace is held by bolts screwed into the enlarged ends from outside the shell; the ends of the brace bear

against washers which can be driven out after the bolts are withdrawn, and the brace can then be removed to a convenient place within the boiler. In the boilers of U. S. S. *Amphitrite* (see Plate IX.) the ends of the shell are stiffened by two angle-irons riveted to them a small distance apart, and the brace is drawn up by nuts against a cross-bar resting on these angle-irons. In the boilers of U. S. S. *Miantonomoh* (see Plate IX.) the tap-bolt passes through a ferrule against which the brace bears; this ferrule is to be filled with red-lead, and is intended to protect the bolt against scale and corrosion.

Figure 114 illustrates a brace used to stay the upper portion of the flat ends of some

Fig. 114.



cylindrical boilers built by R. Napier & Co., Glasgow, in 1870. The ends of the boilers are stiffened by two T-irons ($4\frac{1}{2}'' \times 4\frac{1}{2}''$) spaced 10 inches between centres; bolts, 2 inches in diameter and 21 inches long, are riveted to the T-irons, 20 inches apart; each pair of bolts carries a stout cross-bar secured by nuts; the brace, $2\frac{1}{4}$ inches in diameter, passes through the middle of this cross-bar, the ends being held by cotters; the brace is made in two parts, connected by means of an eye and pin. This brace is easily removed and adjusted to the proper tension, but the work involved in its manufacture makes it rather expensive.

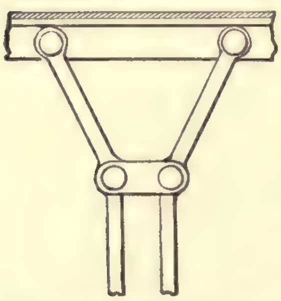
The bracing applied to the boiler on Plate XV. is much used, the T-ends being secured to the angle-irons either by rivets or bolts. This form makes a very stiff brace, and the strain is well distributed over the stayed plate; consequently the braces may be spaced rather wide apart, but it is difficult to remove and replace such heavy braces within the boiler.

The attachment of a brace by means of a single bolt or pin, making a flexible joint, has the great advantage that it allows the brace to adjust itself to the direction of the resultant of the opposing forces, so that it experiences tension only in the direction of its axis; on this account this method of fastening is to be recommended, especially when the braces are very long and relatively slender, and when they are not perpendicular to the stayed surfaces. When such braces are made with jaws or forked ends, which take hold of the lugs or T-irons riveted to the plate (see U. S. S. *Monadnock*, Plate IX.), the place where the forked end joins the body of the brace is apt to be a weak spot; a simple eye-bar is not only free from this weakness, but is cheaper to

make. The eye-bar takes hold of two angle-irons or bracket-plates, placed far enough apart to let the end of the brace pass between them without jamming; the bracket-plates are often made of considerable depth, and are stiffened by tying each pair together by bolts or rivets, using thimbles to keep them the proper distance apart. The bracket-plates are made of the form shown on Plate IX., to make them lighter and to facilitate the removal of the braces.

The brace represented in figure 115 is illustrated in plates accompanying Ledieu's 'Traité élémentaire des Appareils à Vapeur de Navigation,' and, although not commonly applied, may sometimes be used to advantage instead of branch-braces. The short horizontal link resists the normal component of the stress on the braces.

Fig. 115.



In the branch-brace each of the oblique branches is sometimes formed by a pair of separate links; usually, however, each link consists of two rigidly-connected branches, as shown on Plate IX. (U. S. S. *Terror*). Two links are used in order to avoid forked ends. These links have been formed of solid plates, an example of which may be found on Plate XVIII.; these are very stiff, but heavy and clumsy.

Triangular links of the form shown in figure 116 have been used to connect the lower end of braces to the arched crowns of adjacent furnaces. The horizontal bar experiences compression and prevents distortion of the furnace-crowns; but it renders access to the interior over the furnaces through the manholes very difficult, and it is therefore better to rivet a separate stay to the furnaces a little lower down, as shown on Plate XVIII.

In the boilers of U. S. S. *Mohongo* a similar triangular frame was riveted to the furnace-crowns (see figure 117), making the boilers almost inaccessible over the furnaces.

Fig. 116.

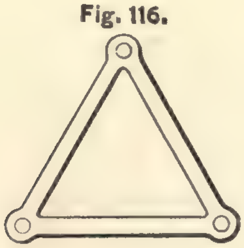
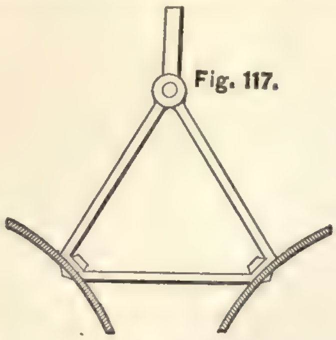


Fig. 117.



Frequently the oblique branches are formed by simply bending a bar and letting the pin of the brace bear directly on this bar at the angle; the ends of the bent bar are

either made with an eye, for the purpose of attaching them by means of a pin, or they are rigidly riveted to the boiler (see figure 118). Such braces are much cheaper and more easily made than those illustrated on Plate XVIII., but they experience irregular bending strains, and they do not take up the strain on the stayed plates as well, and are consequently less reliable and not to be recommended.

The braces should be connected by well-fitting bolts with coarse threads secured by nuts, or by pins secured by cotters or keys; the nut or key does not merely hold the bolt or pin in place, but, when drawn up tight, adds much to the strength of the joint

Fig. 118.

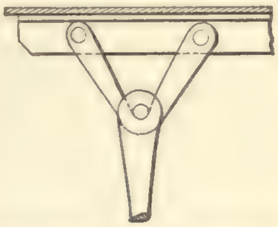


Fig. 119.

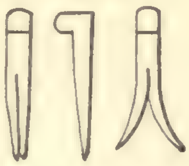
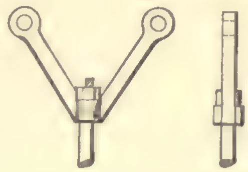


Fig. 120.



by preventing the jaws from spreading or the displacement of the links, so that the pin or bolt experiences simply a shearing stress and not a bending stress. The use of *split pins* (see figure 119) should be avoided, since they rarely fit the holes as well as bolts, and give little or no lateral stiffness to the joint; besides, the split ends are liable to break off when they are opened, after inserting the pin, to prevent working out, or closed for the purpose of backing it out.

In order to facilitate the adjustment of long braces to the proper tension the connection between the branches and the brace is sometimes made in the manner illustrated in figure 120; or the braces are made in halves, connected by a turnbuckle made of brass so that it does not rust fast to the brace. (See Plate XVIII.)

5. Fitting and Adjusting Rod-braces.—Welding should be avoided as much as possible in boiler-braces, for the strength of the brace depends upon the soundness of the weld, which is frequently an uncertain element, and the iron at the weld is much more readily attacked by corrosion than at the parts where the fibre has remained undisturbed.

The ends of long braces have to be forged separately to the required shape; and after being fitted, the threads cut, the pin-holes bored, etc., they are welded to the rods. It is safer to forge rod-braces at first a trifling amount too long, and to adjust them to the exact length by "*upsetting*" the rod. "*Drawing-down*," even to a small extent, should be avoided; in case the brace is found to be too short the rod should be cut and a piece welded in.

The pin-holes in the ends of braces should be bored accurately, so that the pins fit well and are thus subject to a shearing stress and not to a bending stress. In ordinary boiler-work the pin-holes are often not bored at all, but are made by bending a square bar so as to form a loop, and welding the ends together. Figure 121 illustrates a common method of forming the forked end of a brace which takes hold of a T-iron or a single "*crow-foot.*"

The vertical braces that pass between the rows of horizontal tubes are often made of

Fig. 121.

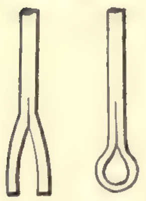


Fig. 122.

flat bars in order to save room. When the manner of attaching the brace to the shell would place its longer side in a transverse direction to the axes of the tubes a half-twist is given to the end of the brace, as shown in figure 122. Sufficient clearance must be allowed between the braces and the tubes so that under the varying strains the braces do not chafe against the tubes and cut them through. In long, horizontal braces the "*sagging*" has to be taken into account. In the rectangular boiler the long, horizontal braces tying the ends of the boiler together are placed slightly above the plane of the shorter, stiffer braces which tie the front and back of the boiler together, and rest on these; in other cases long, horizontal braces are supported in the middle by light hooks suspended from the T-irons above.

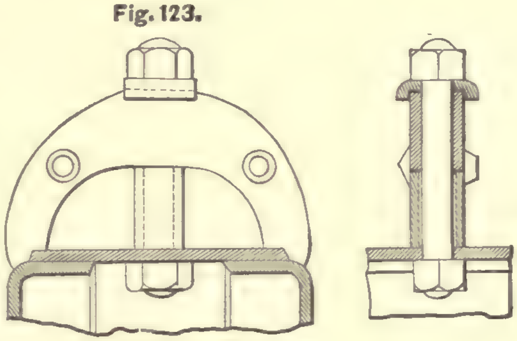
Braces should be set up before the tubes are expanded and before the external seams of the shell are calked. Before setting up the braces of the large flat surfaces of rectangular boilers it is well to shore these up evenly, else there is danger of setting up the braces near the middle of the surface more than those near the sides, thus giving to the surface a "*dished*" form.

To test whether long braces are set up to the same tension, tap each brace at the same distance from the support with a hammer, and note whether the sound is in the same key—the tauter brace vibrates quicker and gives a note of higher key than the slacker one, provided the rods have the same diameter and length.

6. Girder-stays, Gusset-stays, Stay-plates, Stay-domes, etc.—*Girder-stays* are either forged solid (see Plate IX.) or they are made of two plates riveted together at the ends, with distance-pieces between them and a square washer placed on top for the bolt to bear against (see figure 123). A clear space of about $1\frac{1}{2}$ inches should be kept between the girder-stay and the supported plate; to prevent the buckling of the plate in screwing up the bolts tight, ferrules surrounding the bolts are inserted between the plate and the bar, or the bolts pass through short projections forged on the lower side of the bar. The girder should be of such length that its ends rest on the perpen-

dicular plates forming the sides or ends of the back-connection or fire-box, and not on the supported plate. The girder-stays of locomotive fire-boxes extend sometimes through the whole width of the boiler, the ends being riveted or bolted to the shell. Heavy T-irons are also used for girder-stays, and when they are long they are supported in one or several places by braces hung from the top of the shell; the stay-bolts are placed staggering, passing alternately through either flange of the T-iron.

Fig. 123.



The front plate of the back-connection of the boiler illustrated on Plates VIII. and IX. is stayed by a contrivance which may be classed among the girder-stays; the plate is supported by a bolt passing through a wrought-iron frame with four branches, which rest on the plate at places well supported by the furnace-flues and the sides of the back-connection.

Flat surfaces of small area are sufficiently stiffened by angle or T-irons riveted to them, without the use of braces. The flat ends of cylindrical shells have been stiffened in the same manner, but when their diameter is large an awkward strain is thrown on the rivets attaching the heads to the cylindrical shell; in such cases it is better to use *gusset-plates*. These should be secured by double flanges formed either by riveting two angle-irons to the plate or by turning one flange on the plate and riveting an angle-

Fig. 124.

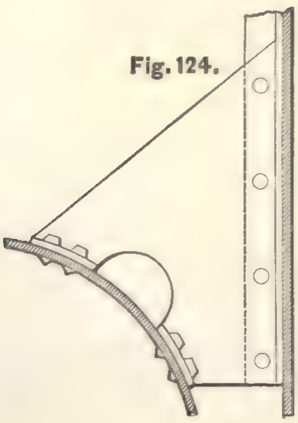
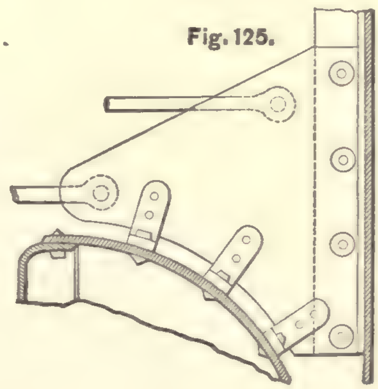


Fig. 125.



iron to the other side; the rivets attaching the two flanges to the shell should be spaced staggering. It is advantageous to extend the length of the gusset along the shell, and

secure it also to the second belt of plates, and not to the first only, although the latter is the usual practice.

The gussets which tie the heads to the cylindrical shell of a boiler are often arranged radially, so that the flanges attaching the gussets to the shell may all be bent to a right angle; but when the continuation of the gussets on the flat ends forms stay-plates for the attachment of braces (see Plate XII.) it is preferable to place them parallel to each other.

Where gussets or stay-plates are attached to heating-surfaces, as to the top of back-connections, portions of the flanges between the rivets are cut away, as in figure 124, or the plates are held by lugs riveted to them (see figure 125); a better plan is shown on Plate VIII., where thimbles surrounding the rivets, and at least one inch long, are placed between the flanges of the angle-irons and the stayed plate; the rivets are spaced staggering, passing alternately through either of the two flanges.

The *stay-domes* which strengthen the front plate of the back-connection of the boiler shown on Plate XII. were formed by pressing the heated plate into a mould, using a spherical shot of suitable diameter as a die, the ends of the plate being held by clamps so as to form a flat flange. These domes were riveted over circular openings cut in the plate of the back-connection. The furnace-tubes and side plates of the back-connection give sufficient stiffness to the plate to support the thrust on the flange of the stay-dome.

7. Experiments on the Shearing Strength of Wrought-iron Bolts.—Experiments on shearing wrought-iron bolts, conducted at the Washington Navy-Yard in 1868, by Chief Engineer William H. Shock, U.S.N., gave the results recorded on Plate XX., where the shearing attachments for single and double shear are likewise illustrated. The Rodman testing-machine was used in making these experiments.

The bolts were of good American commercial iron, not turned. Five sizes of bolts were tested, their diameters being $\frac{1}{2}''$, $\frac{5}{8}''$, $\frac{3}{4}''$, $\frac{7}{8}''$, and $1''$; six specimens of each size were subjected to the single-shear test, and the same number to the double-shear test. The bolts fitted snugly in the respective holes of the shearing attachments, but the latter were made slightly oval, the larger diameter lying in the direction in which the stress was applied. The nuts on the bolts were set up close, but not hard, so as to prevent lateral motion of the two parts of the shearing attachment without producing friction.

The smaller bolts showed, on the whole, a larger shearing strength per square inch of sectional area than the larger bolts; but the decrease in strength was not regular or

uniform. The increase of average strength per square inch of sectional area of the bolts for double-shear over that of single-shear was, for the

$\frac{1}{2}$-inch bolts, 86.2 per cent.
$\frac{5}{8}$-inch bolts, 97.0 per cent.
$\frac{3}{4}$-inch bolts, 101.1 per cent.
$\frac{7}{8}$-inch bolts, 82.6 per cent.
1-inch bolts, 85.0 per cent.

Average for all sizes of bolts, 90.2 per cent.

In experiments No. 20 and 21 of the double-shear test the nuts were not screwed up close, and the results show a remarkable decrease of strength in comparison with the four other bolts of the same diameter subjected to double-shear. In experiment No. 20 this decrease of strength amounted to 9.1 per cent. of the average result given by the four other bolts, and to 7.1 per cent. of the least result given by the bolts of the same series; and in experiment No. 21 this decrease of strength amounted to 13.8 per cent. and 11.9 per cent. respectively.

8. Experiments made to determine the proper Dimensions of Pins, Eyes, and Shanks of Boiler-braces.—In the course of the years 1878–79 experiments were conducted at the Navy-Yard, Washington, D. C., under the direction of the Bureau of Steam-Engineering, by a board consisting of Chief Engineer Jas. P. Sprague, U.S.N., and Passed Assistant Engineer George E. Tower, U.S.N., the object being to ascertain the proper proportions for the ends of boiler-braces. The Rodman testing-machine represented on Plate I. was used in making these experiments.

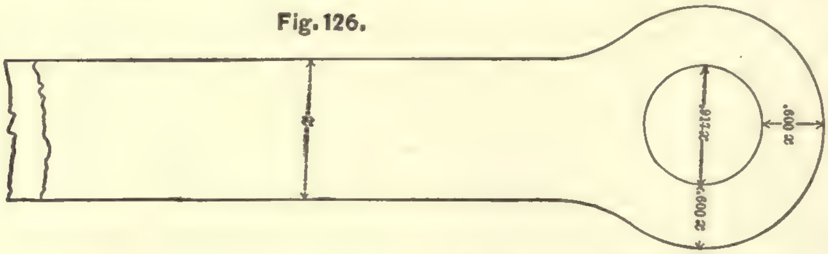
The test-specimens were made in the form of eye-bars, which were secured by accurately-fitted iron or steel pins to jaws attached to the testing-machine, so that the pins were subjected to double-shear. The proportions of the eye-bars in each series of experiments were gradually changed till the metal at the sides and at the crown of the hole and in the shank of the brace appeared to be very nearly equally strained when rupture took place.

In the first series of experiments the specimens were made of flat iron bars $\frac{5}{8}$ inch thick and from $1\frac{3}{16}$ to $1\frac{1}{4}$ inches wide. The eyes were formed by drawing out the bar under the hammer, bending and welding it around a mandrel $\frac{1}{8}$ inch less in diameter than the finished hole, then reaming out the hole to fit the pin; the rest being finished to the proper size in a shaping-machine. The surfaces were planed and finished, and careful examination did not reveal any defect in the welding. Nevertheless three of the fifteen specimens broke in the weld, and some of the eyes made from the same bar

broke at greatly different strains, indicating that the iron had been injured somewhat in welding. The depth of the eye was in every case equal to the thickness of the bar.

The following proportions are submitted by the board, "as those which will give nearly a uniform strength in the eye, slightly in excess of that of the shank, supposing the weld to be perfect and the quality not to be materially affected in welding and working; these proportions will apply until the thickness of the bar is equal to its breadth; with a steel pin of proper tensile strength its diameter can be reduced to 65 per cent. of the breadth of the bar, with the same results," (see figure 126:)

Fig. 126.



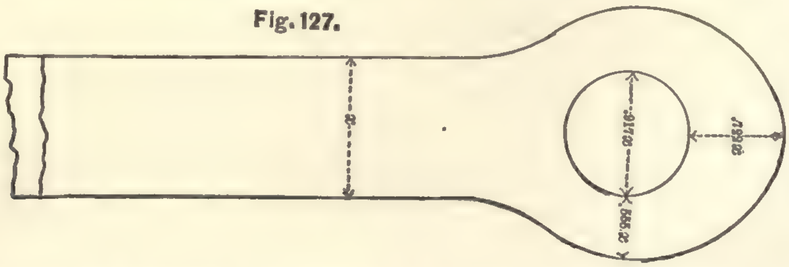
Breadth of shank of iron bar	=	x
Diameter of iron pin	=	$.917\ x$
Width of metal on each side of eye	=	$.600\ x$
Width of metal at crown of eye	=	$.600\ x$

Depth of eye equal to thickness of bar.

In the second series of experiments the eyes were cut from flat bars, $\frac{5}{8}$ inch thick and $2\frac{5}{8}$ inches wide, *without forging.* The specimens were planed smooth on both sides to bring them to the proper thickness. The holes were drilled and reamed to fit the pins accurately. The specimens were then put on mandrels and cut out to the required form in the shaping-machine.

The following proportions are submitted by the board for eye-bars made in this man-

Fig. 127.



ner, as approximating as nearly as possible to a uniform strength in all parts, the depth of the eye being equal to the thickness of the bar. These proportions will apply until

the thickness of the bar is equal to its breadth. With a steel pin the diameter can be reduced to 65 per cent. of the breadth of the bar. (See figure 127.)

Breadth of shank of iron bar	=	x
Diameter of iron pin	=	$.917\,x$
Width of metal on each side of eye	=	$.555\,x$
Width of metal at crown of eye	=	$.722\,x$

Depth of eye equal to thickness of bar.

A third series of experiments was made with specimens cut from flat bars and having similar dimensions as the specimens tested in the second series of experiments, but with iron or steel pins of increased diameters. The result showed that, by using iron and steel pins having the respective proportions deduced from the first and second series of experiments, the conditions of strain on the eye-bars are not materially altered.

A fourth series of experiments was made with eye-bars made of round iron slightly larger than the required size. "The eye was formed (solid) by upsetting the end of the bar and forging to the required shape; the eye and bar were brought as nearly as possible to given dimensions in the lathe and planer. The hole in the eye was drilled, and the pin made to fit easily but not loose."

The following proportions are recommended by the Board for eye-bars formed in this manner, the depth of the eye being equal to the diameter of the bar:

Area of cross-section of shank of round iron bar	=	y^2
Area of cross-section of iron pin	=	y^2
Area of cross-section of metal on each side of eye	=	$.74\,y^2$
Area of cross-section of metal at crown of eye	=	$.90\,y^2$

(*See* '*Report on Experiments to ascertain Proportions for the Ends of Boiler-braces.*' *Washington, D. C., November* 24, 1879.)

9. Experiments on Screw Stay-bolts.—For the purpose of determining the strength and holding power of screw stay-bolts for boilers under different conditions, experiments were conducted at the Navy-Yard, Washington, D. C., in the course of the year 1879, under the direction of the Bureau of Steam-Engineering, by a board consisting of Chief Engineer James P. Sprague, U.S.N., and Passed Assistant Engineer George E. Tower, U.S.N.

These experiments were of two kinds.

In the first place a series of tests was made "to determine the comparative force necessary to pull screw stay-bolts of iron and copper through iron, low-steel, and cop-

per boiler-plates." The Rodman testing-machine illustrated on Plate I. was used in making these tests.

"Three trials each were first made with $\frac{1}{2}''$ iron plates and $1''$ iron stay-bolts, not riveted, and riveted over with the ordinary thin or low conical head, simply arranged so as to show the actual strength to resist pulling through the plate, the supports consisting of heavy plates with a hole $1\frac{3}{4}''$ in diameter; the boiler-plate resting upon the heavy plate and the stay-bolt adjusted to the centre of the hole, thus allowing the bolt to have a clear space around it equal to the overlapping of the riveted head on the boiler-plate. The bolts not riveted drew out at an average strain of 32,785 pounds; those riveted with the low conical head, made according to general practice by leaving three threads through to form the head, required an average strain of 35,033 pounds to draw them through the plate; the rivet-head giving an additional strength of 2,248 pounds in a $1''$ stay-bolt.

"In testing those with low conical heads it was observed that the bulging of the plates caused the lap of the rivet-head on the plate to commence giving way or break off some time before the maximum strain was reached, thus leaving more for the threads on the bolts to sustain. As the strain and bulge of the plates increased, the plate around the bolt turned downward and outward until the threads in the plate almost entirely cleared those on the bolts, so that in almost every case there were only from one to two threads stripped or injured on the bolt when it drew out; therefore it was deemed advisable to form the head in a different manner, and, after several experiments, it was decided that the rivet-head should be made as follows: First, by leaving as much of the bolt through the plate as could be riveted over without injury to the iron, which was, in case of the excellent iron being used, equal in length to about one-half the diameter of the bolt. This was riveted over in the following manner: A few quick, sharp blows were struck on the end, slightly upsetting the iron; the head was then formed to shape with a button-head set made to a spherical segment.

"It was found that this could be done in nearly the same time as that used in riveting the ordinary low conical stay-bolt heads at the Washington yard, and with much less injury to the iron; also, that it only required one riveter and a helper, whereas by the old method two riveters were used.

"Three trials each were then made with $\frac{1}{2}''$ iron plates and $1''$ iron stay-bolts: not riveted; riveted with ordinary low conical head, with three threads left through for riveting; riveted with button-head, a little over five threads left through for riveting; and with button-head, the size of stay-bolt being increased to $1\frac{1}{4}''$.

"Each end of the stay-bolt was secured, in the manner specified, in the centre of a

square plate, which was supported by four bolts, one in each corner, by means of which it was held in the testing-machine. These supporting-bolts were placed, in different experiments, four and five inches apart from centre to centre, equally distant from the stay-bolt.

"The average ultimate strain required to pull the above bolts through the $\frac{1}{2}''$ plate was as follows:

WITH SUPPORTS 4″ FROM CENTRE TO CENTRE.

	Pounds.
1″ bolt, not riveted	21,970
1″ bolt, ordinary low conical head, three threads left through for riveting	25,147
1″ bolt, button-head; length of bolt left through for riveting equal to $\frac{7}{16}$ diameter of bolt	33,791
$1\frac{1}{4}''$ bolt, button-head; length left through for riveting equal to $\frac{1}{2}$ diameter of bolt	38,885

WITH SUPPORTS 5″ FROM CENTRE TO CENTRE.

1″ bolt, ordinary low conical head	22,137
1″ bolt, button-head; length left through for riveting equal to $\frac{7}{16}$ diameter of bolt	31,282
$1\frac{1}{4}''$ bolt, button-head; length left through for riveting equal to $\frac{1}{2}$ diameter of bolt	35,812

"The great increase of holding power given to screw stay-bolts by forming the riveted head with a button-head set being demonstrated by these tests, further experiments were made with iron, steel, and copper plates and stay-bolts secured in the same manner, for the purpose of determining the best proportions of diameter of stay-bolts to thickness of plate under different conditions

"In comparing the results of three different thicknesses in each case ($\frac{1}{4}''$, $\frac{3}{8}''$, $\frac{1}{2}''$ plate) of iron plates and iron bolts, steel plates and iron bolts, steel plates and steel bolts, the diameter of the bolts being 1″, $1\frac{1}{8}''$, and $1\frac{1}{4}''$, their distance apart and conditions of trial being the same, it was found that in the case of the iron plates and iron bolts the strain required to draw the bolts through the plates was equal to 74.77 per cent. of the tensile strength of the bolt, with the steel plates and iron bolts 77.36 per cent., and with the steel plate and steel bolts 85.42 per cent."

In the next series of experiments the plates and stay-bolts were arranged so as to represent a portion of the wall of a fire-box, and water-pressure was used to produce the strain.

Iron, steel, and copper plates were used, varying from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch in thickness. The iron and steel screw stay-bolts were spaced from 4 inches to 8 inches apart, and, after being screwed through the plates, their ends were secured either by riveting them over with a button-head set or by means of nuts and washers.

The Board conclude their report on these experiments with the following recommendations, viz.:

"After a careful examination of the results of these experiments in particular we are satisfied that the following formulæ will correctly and safely represent the working strength of good material in flat surfaces, supported by screw stay-bolts with riveted button-shaped heads or with nuts, when the thickness of the plates forming said surfaces and the screw stay-bolts are made in accordance with the dimensions and conditions given in Table Y. W = safe working pressure; T = thickness of plate; d = distance from centre to centre of stay-bolt:

For iron plates and iron bolts.................... $W = 24,000 \dfrac{T^2}{d^2}$

For low-steel plates and iron bolts.................... $W = 25,000 \dfrac{T^2}{d^2}$

For low-steel plates and low-steel bolts.................... $W = 28,000 \dfrac{T^2}{d^2}$

For iron plates and iron bolts, with nuts.................... $W = 40,000 \dfrac{T^2}{d^2}$

For copper plates and iron bolts.................... $W = 14,500 \dfrac{T^2}{d^2}$

"To obtain the ultimate bursting pressure multiply the results of the above formulæ by 8, which is the factor of safety used.

"The rivet-heads to be a segment of a sphere, formed by first upsetting the end of the bolt with a few quick, sharp blows of the hammer, then finished to shape with the hammer and button-head set. Where nuts *can* be used instead of riveted heads they should be of the standard size, suited to the diameter of the bolt, faced on the side bearing on the plate, and dished out so as to form an annular bearing-surface of as large a diameter as the nut will allow, and of a breadth and depth given in the table. Before securing the nut in place the dished portion should be filled with red-lead putty made stiff with *fine* iron borings."

TABLE Y.

DIMENSIONS AND CONDITIONS FOR MAKING IRON AND LOW-STEEL SCREW STAY-BOLTS FOR FLAT SURFACES SUBJECT TO INTERNAL PRESSURE FOR DISTANCES RANGING FROM FOUR TO EIGHT INCHES (INCLUSIVE) FROM CENTRE TO CENTRE OF STAY-BOLTS.

Thickness of plate.	Diameter of bolt outside of thread.	Number of threads per inch.	Length of bolt left through for riveting in fractions of diameter of bolt.	Height of rivet-head when finished.	Diameter of base of rivet-head not to exceed when finished	Nuts.	
						Breadth of annular bearing-surface.	Dished out to a depth of
$\frac{1}{4}''$	$1''$	14	$\frac{1}{2}$	$\frac{7}{16}''$	$1\frac{5}{16}''$	$\frac{1}{16}''$	$\frac{1}{16}''$
$\frac{3}{8}''$	$1\frac{1}{8}''$	14	$\frac{1}{2}$	$\frac{1}{2}''$	$1\frac{9}{16}''$	$\frac{1}{8}''$	$\frac{1}{16}''$
$\frac{1}{2}''$	$1\frac{1}{4}''$	12	$\frac{1}{2}$	$\frac{9}{16}''$	$1\frac{3}{4}''$	$\frac{3}{16}''$	$\frac{3}{32}''$
$\frac{5}{8}''$	$1\frac{3}{8}''$	12	$\frac{1}{2}$	$\frac{5}{8}''$	$1\frac{7}{8}''$	$\frac{1}{4}''$	$\frac{3}{32}''$

CHAPTER XI.

FLUES AND TUBES.

1. Flue-boilers.—The flues or channels for the passage of the products of combustion from the furnace to the chimney were at first made very large in marine boilers, so as to give easy access for cleaning and repairs, and, in order to get a great amount of heating-surface, these passages were often made very tortuous. While the pressures of steam used in marine boilers exceeded but little the atmospheric pressure the flues were frequently made with flat sides (see figure 1, Plate XXI.); but with increased steam-pressures flues of a circular cross-section have come into general use. The longitudinal seams of these flues are either lap-welded or riveted. Stationary flue-boilers are frequently made very long, with one or two large circular or elliptical flues running through the whole length of the boiler. The length of marine boilers being limited by the available space, the required amount of heating-surface is obtained in them by using return-flues, and by decreasing their diameter and increasing their number (see figure 2, Plate XXI.)

In the *drop-flue* boiler (see figure 3, Plate XXI.) the products of combustion pursue a downward course in their passage from the furnace to the chimney; by this arrangement the cooler gases are brought in contact with surfaces surrounded by the less heated water at the bottom of the boiler, and consequently part more readily with their heat.

The efficiency of stationary flue-boilers has been greatly increased by the introduction of the so-called *Galloway tubes;* these are conical tubes placed with the larger end uppermost across the flues, sometimes slightly inclined. Besides furnishing additional very efficient heating-surface they facilitate greatly the circulation of the water and act as stiff stays; in this latter capacity they are particularly useful when the flues have an elliptical cross-section. The introduction of these tubes into old flue-boilers has often produced a remarkable improvement in their steaming capacity; but, on the other hand, they make the flues more difficult to clean and repair, so that the accumulation of soot and dirt may actually cause a diminution of the efficiency of the heating-surface, while, at the same time, the obstructions to the draught diminish the rate of combustion. Similar tubes are sometimes placed in the back-connections of marine

boilers, especially when there is one back-connection common to all the furnaces of a boiler.

Flue-boilers are bulky and heavy, and the large amount of water contained in them makes it impossible to get up steam quickly. To remedy these defects, which are often of vital importance in a marine boiler, it became necessary to reduce the length of the flues, and to increase the proportion of their superficial area to their cross-area by subdividing each flue into a number of narrow passages.

In the *Lamb and Sumner* boiler the flues returned over the furnaces and consisted of a number of narrow, flat-sided passages, separated by equally narrow water-spaces, from 1½ to 2 inches wide in the clear, and from 36 to 45 inches high. The flat sides were held by stay-rivets passing through the smoke-passages. These boilers were in great favor some years ago; the flat sides of the water-spaces were easily scaled, and the flues were not so soon obstructed by soot as small tubes; but the narrow passages were inaccessible for repairs in case of leaks, and corrosion destroyed them rapidly. These boilers have now gone out of use.

At the present day it is the nearly universal practice to get the principal quantity of heating-surface in marine boilers by the use of cylindrical tubes varying from 2 to 4 inches in diameter.

2. Relative Advantages of Flues and Tubes for Marine Boilers.—The principal advantages possessed by tubular over flue boilers may be shortly summed up as follows: Less weight and space is required for boilers of equal economic and potential evaporative efficiency; steam can be raised rapidly after the fires are started, in consequence of the relatively small weight of water contained in the tubular boiler in proportion to the extent of heating-surface; the small tubes have far greater strength than flues; the tubes are less liable to leakage from the absence of riveted joints; they can be made of material not liable to corrosion, and are easily removed and replaced; the escape of steam or water from a ruptured tube seldom produces serious effects, and the leak can often be temporarily stopped without interrupting the working of the boiler.

On the other hand, crowding the numerous tubes into a narrow space, and the rapid formation of steam on their surfaces, often cause foaming or priming, affecting very unfavorably the economic performance of the engine; a large portion of the heating-surfaces is inaccessible for cleaning, so that the accumulation of scale and other foreign matter soon impairs the evaporative efficiency of the surfaces, and causes the destruction of the boiler by corrosion or the burning of the metal.

3. Various Types of Tubular Boilers.—There exists great variety in the arrangement of tubes within the boiler: the hot gases pass either through them or around

them; tubes may be horizontal, vertical, or inclined, and may be arranged above, behind, or at the sides of the furnaces; they are generally straight, but bent and spiral tubes are employed in some types of boilers. Examples of different arrangements of tubes in marine boilers have been given and their advantages and disadvantages discussed in chapter vii.

The considerations governing the location and position of the tubes in marine boilers may be summed up as follows: When the room in the length and breadth of the vessel available for the boilers is limited the tubes must be arranged directly over the furnaces; when, on the contrary, it is essential to keep the boilers as low as possible, the tubes have to be arranged behind or alongside the furnaces. Every change in the direction of the current of the hot gases passing from the furnace to the chimney involves a loss of head, or, in other words, diminishes the draught, and consequently the maximum rate of combustion. The resistance to the flow of gases *through* a tube is mainly due to friction against its inner surface; the resistance to the flow of gases *between* a nest of water-tubes is relatively much greater, being due to friction against the outer surfaces of the tubes, to the loss of head produced by the successive changes in the cross-area of the passages, and to the counter-currents caused by the impingement of the gases on the tubes. The evaporative efficiency of the vertical water-tube is superior to that of the fire-tube, because the hot gases impinging on the surface of the former part with their heat much more readily than the gases which move in a direction parallel to the axis of the fire-tube. The evaporative efficiency of vertical fire-tubes is inferior to that of horizontal fire-tubes, because the steam escapes more readily from the most efficient portion—*i.e.*, the top—of the latter, and the tendency to an equalization of the temperature of the mass of gases by convection is greater in the horizontal than in the vertical fire-tube; for the gases which are cooled down by contact with the upper portions of the surface of the horizontal tube sink by gravity and are replaced by hotter gases, while in the vertical tube the gases occupying the central part of the tube are likely to pass through the tube without coming in contact with its sides. Horizontal water-tubes are inefficient and dangerous with a rapid evaporation, on account of the difficulty which the steam experiences in escaping from them. Externally-heated horizontal tubes can, however, be used safely for the purpose of drying or superheating steam. Scale is easily removed from the inner surface of water-tubes, but fire-tubes are more easily swept of soot and ashes. With vertical tubes the water-level can be safely carried below the upper tube-sheet, while horizontal tubes are quickly destroyed when the upper rows are bared of water.

4. Dimensions and Spacing of Tubes.—The width of the space available for

each nest of tubes is generally limited by the width of the furnace; and its height and the length of the tubes are dependent not only on the dimensions of the shell of the boiler, but also on economical considerations. In proportioning the dimensions of the tubes and their spacing the following conditions must be kept in view:

First. The opening through or between the tubes must be sufficient for the passage of the products of combustion; the calorimeter determines to a great extent the rate of combustion in the furnace, and varies in marine boilers from $\frac{1}{5}$ to $\frac{1}{8}$ of the area of the grate-surface.

Second. The tubes must present a sufficient amount of heating-surface. The ratio of the heating-surface to the rate of combustion affects the economic and potential evaporative efficiency of the boiler; and the evaporative efficiency of the tube-surface decreases rapidly from the end where the gases enter to where they are discharged into the uptake. In the ordinary types of return-tubular boilers, in which the total heating-surface is equal to 25 times the grate-surface, the proportion of the tube-surface to the grate-surface is very nearly as 18 to 1. The heating-surface of a tube is to be calculated for the side in contact with the hot gases; therefore it depends on the outer circumference of a water-tube, and on the inner circumference of a fire-tube.

Third. The spaces between the tubes must be arranged with regard to facility for scaling and cleaning, and to the free escape of the steam as soon as formed. The upper rows of horizontal fire-tubes and the upper part of vertical tubes are surrounded or filled by the mass of steam-bubbles rising from the lower heating-surfaces, and are on this account less efficient as heating-surfaces. Isherwood found by experiment that the gases emerging from the upper rows of tubes were often nearly 300° Fahr. hotter than those leaving the lower rows of tubes. For this reason it is advantageous to make the nest of tubes as low as possible.

The outside diameter of the vertical water-tubes in the Martin boiler (see Plate VI.) is generally 2 inches, and they are spaced from 3 inches to $3\frac{1}{4}$ inches apart from centre to centre on a line across the tube-box; when the clear space between two adjoining tubes is made less than one inch the draught of the boiler becomes seriously impaired. On a line in the direction of the length of the tube-box, the closeness of the spacing of the tubes is limited only by the possibility of boring the holes in the tube-plates without impairing the stiffness of the plates too much; with 2-inch tubes the distance between the centres is seldom less than $2\frac{11}{16}$ inches. The length of the tubes depends on the amount of heating-surface required, but is limited by the height of the boiler; the evaporative efficiency of short tubes is greater than that of longer tubes having the same diameter and presenting an equal amount of heating-surface.

In the boiler represented on Plate VI. the tubes are 2 inches in diameter and 32 inches long between the tube-sheets; they are spaced $3\frac{1}{4}$ inches apart from centre to centre across the tube-boxes, and $2\frac{11}{16}$ inches apart from centre to centre in the rows running lengthwise the tube-boxes. Each tube-box is of the same width as the furnaces—viz., 36 inches—and is $85\frac{1}{2}$ inches long, containing in this space 306 brass tubes with an aggregate heating-surface of 427.25 square feet.

These tubes have sometimes been arranged so that the longitudinal rows formed zigzag lines, in order that the gases might impinge on a greater amount of surface; but what is gained in evaporative efficiency of tube-surface in such a case is lost in the rate of combustion. The most serious objection to this arrangement is the impossibility of sweeping the spaces between the tubes properly.

The diameter of fire-tubes in marine boilers varies ordinarily between $2\frac{1}{2}$ inches and 4 inches. Horizontal tubes of smaller diameter than $2\frac{1}{2}$ inches would soon become choked with ashes and soot, unless forced draught is used, as in locomotives, when the diameter is reduced sometimes to $1\frac{1}{2}$ inches. Vertical fire-tubes may be made of smaller diameter than horizontal tubes, since they are not obstructed by soot and ashes like the latter. When bituminous coal is the fuel used tubes of larger diameter become necessary than when anthracite is burned, on account of the great quantity of soot produced by the former coal. Large tubes offer less resistance to the flow of the gases, and admit of a higher rate of combustion with natural draught, than smaller ones; but with the latter a larger amount of heating-surface can be got in a given space. When the diameter of the fire-tube is increased it becomes necessary to increase its length in the same proportion, in order to preserve the same ratio between the surface and the cross-area of the tube, or, in other words, between the heating-surface and the quantity of gas passing through each tube.

Experiments by Dewrance, Woods, and C. W. Williams demonstrated the rapid decrease in the evaporative efficiency of each additional length of tubes. After a certain limit is reached the gain in the evaporative efficiency of a tube through an increase of its length, and consequently of its surface, is trifling compared with the additional bulk, weight, and cost of the boiler, while the additional friction retards somewhat the draught. Since for equal economic evaporative efficiency the amount of heating-surface must be proportioned to the quantity of hot gases in contact with it, the length of the tube must depend on the diameter of the tube and the rate of combustion. In locomotive boilers, with forced draught, the length of tubes is made often 120 times their diameter. Wilson recommends that with natural draught the length of tubes should not be greater than 24 times their diameter. This is, however, less than the usual prac-

tice, and Isherwood says: "For a tube 3 inches diameter a length of 38 diameters will be found a good proportion with a rate of combustion exceeding 12 lbs. of anthracite per hour in the hold of a vessel."

The clear space between adjoining horizontal fire-tubes varies between one-half and one-third the diameter of the tubes. To facilitate the washing and the scaling between the tubes, as well as the escape of the steam-bubbles as soon as generated, horizontal tubes in marine boilers should always be arranged in vertical rows, and not in diagonal or zigzag rows, which is sometimes done for the purpose of crowding a greater number of tubes into a given space. In locomotive boilers, where fresh water is used and the steam generated on the furnace-crown has not to pass between the rows of tubes, the latter are frequently arranged in zigzag lines.

In *Stimer's differential tubular boiler* the horizontal fire-tubes in each successive horizontal row, from the bottom upwards, decreased in diameter $\frac{1}{8}$ inch. The boilers of U. S. S. *Tippecanoe* and class had eight horizontal rows of tubes over each furnace; the outside diameter of the tubes was $3\frac{1}{2}$ inches in the bottom row and $2\frac{5}{8}$ inches in the top row; the spacing of the tubes in a horizontal direction was uniform—viz., $4\frac{3}{4}$ inches from centre to centre. This arrangement facilitates greatly the escape of steam, and to some extent the scaling of the tubes, and was also intended to equalize the evaporative efficiency of the heating-surface in each horizontal row of tubes; but its practical disadvantages are great—viz., to form the holes eight sizes of drills or eight adjustments of the boring-cutters are required; eight sizes of tubes are used, and three or four sizes of expanding-tools; spare tubes and expanding-tools of assorted sizes have to be carried, and tube-brushes of assorted sizes are used. With these drawbacks it is not strange that the system has not come into favor.

When a large amount of heating-surface is required it is often difficult to proportion the number and dimensions of the tubes in such a manner in the given space as to get at the same time the best ratio of calorimeter to grate-surface. In such a case the calorimeter of fire-tubes may be reduced by driving ferrules into the ends of the tubes, at the back end of return-tube boilers, and at the front end of locomotive boilers. In the latter boilers, when iron tubes are used, their diameter is sometimes reduced at the front end by swaging, as illustrated on Plate XXIV. When the opening through the tubes is contracted by these means the sweeping of the tubes is made more difficult; the effect of the ferrules in increasing the holding power of the tubes in the tube-plates will be discussed further on.

5. Iron, Steel, Brass, and Copper Tubes.—The tubes of marine boilers are generally made of brass or iron; steel tubes have also been introduced of late. Copper

tubes were formerly used for locomotive boilers, but they wore out rapidly in consequence of the mechanical action of the cinders carried through them at a great velocity by the strong draught; the great difference in the expansion of iron and copper by heat produces also inconveniences in the combination of the two metals in steam boilers. The use of copper tubes in marine boilers is prevented by the lively galvanic action which takes place when copper is in contact with iron in the presence of salt water; they are used, however, sometimes in the steam-space as superheating-tubes, for which purpose the great thermal conductivity of copper and its freedom from corrosion give them great advantages.

Lap-welded wrought-iron tubes are still extensively used in boilers of merchant vessels, but seamless drawn-brass tubes are now almost exclusively used in the boilers of naval vessels. Brass tubes possess many of the advantages of copper tubes, without their disadvantages: they are very ductile, their thermal conductivity is greater than that of iron, and they expand less under the influence of heat than copper; they suffer little from wear, are not subject to corrosion, and do not appear to produce serious galvanic action in marine boilers. Iron tubes have the advantage of lower first cost over brass tubes. Since iron tubes are not so easily injured by burning as brass tubes when the water-level falls below the tubes, a few of them are often used as stay-tubes in horizontal-tubular boilers to hold the tube-sheets, while the principal portion of the tubes is of brass. For vertical water-tubes brass should always be used, because iron tubes are rapidly corroded by the sulphuric acid which is distilled from the soot by moisture, runs down the tubes, and collects at their lower end.

With vertical brass tubes the water-level can be carried safely below the upper tube-plate, as was proved by several interesting experiments conducted by Chief Engineer Isherwood, U.S.N., and recorded in 'Experimental Researches,' vol. ii. In the trial of the vertical water-tube boiler of the U. S. S. *Wyoming* the water-level was carried, at different times, 7½, 15, and 22½ inches below the top tube-plate. "The whole length of the tubes, which were of seamless brass, was 30 inches. The only damage done was when the water was carried 22½ inches below the top tube-plate, and then, after a trial of 72 consecutive hours, burning at the rate of 15.77 lbs. of anthracite per square foot of grate per hour, the joints of only the two rows of tubes next the back smoke-connection were loosened. Neither the brass of the tubes nor the iron of the tube-plate and of the exposed portions of the back smoke-connections was in the least degree injured."

Iron tubes are more apt to be injured than brass tubes in the process of securing them in the tube-sheets by expanding their ends, and leakage with its attendant evils is

more frequent with them. Iron tubes, being relatively thin, are destroyed by corrosion much sooner than the plates of boilers. The thickness of boiler-tubes varies from No. 8 to 14 of the Birmingham gauge, according to their diameter, the material of which they are made, the steam-pressure and the kind of pressure, bursting or collapsing, to which they are exposed.

Coppered and tinned iron tubes have been tried, but they have not been long enough in use to warrant an opinion regarding their durability.

Tubes made of soft steel are either lap-welded or drawn seamless. They are more expensive than iron tubes, and whether they can be made lighter than the latter depends principally on their liability to corrosion, regarding which fact opinions are much divided.

When the tubes are new and clean their thickness and the thermal conductivity of the metal of which they are composed exert, no doubt, an influence on their evaporative efficiency ; but as soon as their surfaces become covered with deposits of soot and scale they become of equal value in this respect.

Drawn seamless tubes are made from short cylinders through which a small hole has been bored or left in casting. The cylinder, being passed through several sets of dies very slightly decreasing in size, and over mandrels very gradually increasing in diameter, is, by a succession of steps and, in the case of steel tubes, after frequently undergoing the annealing process, drawn out into a long, thin tube of the desired dimensions. The process is not severe as long as the dies are in good order, but when they are in the least degree rough great heat is evolved in the passage of the metal. An objection to the method in the case of brass is that the smallest defect is drawn out into a scratch which becomes a source of weakness. Latent defects, however, can be discovered in the testing which all tubes should undergo at the works ; this test should have reference to the use to which the tubes are to be put—those intended for water-tubes should withstand an internal bursting pressure, while those intended for fire-tubes must be able to resist collapse.

Copper and brass tubes were at first made of long, narrow sheets bent into the cylindrical form and brazed at the joint. Wrought-iron ones are now constructed of narrow sheets brought to a welding-heat and passed through rollers. Drawn tubes are generally slightly conical to permit their being easily delivered from the mandrel ; and this feature has been exaggerated by some inventors, who make the outside diameters of tubes which are intended to be removable for the purpose of scaling $\frac{1}{8}$ inch larger at the front than at the back end.

TABLE XXXIII.

SIZES AND WEIGHTS OF LAP-WELDED IRON BOILER-TUBES OF STANDARD GAUGE MANUFACTURED BY THE NATIONAL TUBE WORKS COMPANY.

Outside diameter.	Thickness.		Weight per foot.
Inches.	Birmingham wire-gauge.	Inches.	Pounds.
$1\frac{1}{2}$	14	.0875	1.25
$1\frac{3}{4}$	13	.1000	1.60
2	13	.1000	2.00
$2\frac{1}{4}$	13	.1000	2.10
$2\frac{1}{2}$	12	.1125	2.75
$2\frac{3}{4}$	12	.1125	3.00
3	12	.1125	3.33
$3\frac{1}{4}$	11	.1250	4.00
$3\frac{1}{2}$	11	.1250	4.33
$3\frac{3}{4}$	11	.1250	4.63
4	10	.1406	5.50
$4\frac{1}{2}$	10	.1406	6.00
5	9	.1563	7.25
6	8	.1719	9.33
7	8	.1719	12.50
8	8	.1719	15.00
9	7	.1875	17.31
10	6	.2031	20.80

These tubes are made of the best American charcoal hammered iron and are stamped ◊. The greatest regular length of these tubes is 18 feet; lap-welded tubes of any thickness and size up to 18 inches diameter, and of a length exceeding 18 feet, manufactured to order.

Lap-welded steel boiler-tubes are made from $1\frac{1}{2}$ to 18 inches in diameter.

TABLE XXXIV.

LAP-WELDED AMERICAN CHARCOAL-IRON BOILER-TUBES MANUFACTURED BY MORRIS, TASKER & CO., 1877.

Table of Standard Dimensions.

External diameter. Inches.	Standard thickness. Inches.	Nearest B. W. G.	Internal circumference. Inches.	External circumference. Inches.	Internal area of cross-section. Square inches.	External area of cross-section. Square inches.	Weight per foot. Pounds.
1	.072	15	2.689	3.142	0.575	0.785	0.708
1¼	.072	15	3.474	3.927	0.960	1.227	0.900
1½	.083	14	4.191	4.712	1.396	1.767	1.250
1¾	.095	13	4.901	5.498	1.911	2.405	1.665
2	.098	13	5.667	6.283	2.556	3.142	1.981
2¼	.098	13	6.484	7.069	3.314	3.976	2.238
2½	.109	12	7.172	7.854	4.094	4.909	2.755
2¾	.109	12	7.957	8.639	5.039	5.940	3.045
3	.109	12	8.743	9.425	6.083	7.069	3.333
3¼	.119	11	9.462	10.210	7.125	8.296	3.958
3½	.119	11	10.248	10.995	8.357	9.621	4.272
3¾	.119	11	11.033	11.781	9.687	11.045	4.590
4	.130	10	11.753	12.566	10.992	12.566	5.320
4½	.130	10	13.323	14.137	14.126	15.904	6.010
5	.140	9½	14.818	15.708	17.497	19.635	7.226
6	.151	9	17.904	18.849	25.509	28.274	9.346
7	.172	8½	20.914	21.991	34.805	38.484	12.435
8	.182	8	23.989	25.132	45.795	50.265	15.109
9	.193	7½	27.055	28.274	58.291	63.617	18.002
10	.214	6½	30.074	31.416	71.975	78.540	22.190
11	.220	5	33.175	34.557	87.479	95.033	25.489
12	.229	4½	36.260	37.699	103.749	113.097	28.516
13	.238	4	39.345	40.840	123.187	132.732	32.208
14	.248	3½	42.414	43.982	143.189	153.938	36.271
15	.259	3	45.496	47.124	164.718	176.715	40.612
16	.271	2½	48.562	50.265	187.667	201.062	45.199
17	.284	2	51.662	53.407	212.227	226.980	49.902
18	.292	1½	54.714	56.548	238.224	254.469	54.816
19	.300	1	57.805	59.690	265.903	283.529	59.479
20	.320	½	60.821	62.832	294.373	314.159	66.765
21	.340	0	63.837	65.973	324.311	346.361	73.404

The thickness of tubes can be varied to order. Tubes cut to specific lengths to suit purchasers; lengths greater than eighteen feet at special rates.

TABLE XXXV.

REGULAR SIZES AND WEIGHTS OF SEAMLESS DRAWN BRASS AND COPPER TUBES MANUFACTURED BY AMERICAN TUBE-WORKS, BOSTON, MASS., 1879.

Outside diameter. Inches.	Length. Feet.	Thickness. Stub's W. G.	Weight per foot. Pounds. *Brass.*	*Copper.*
$\frac{5}{8}$	12	18	0.32	0.34
$\frac{3}{4}$	12	17	0.47	0.49
$\frac{13}{16}$	10	17	0.50	0.53
$\frac{7}{8}$	10	17	0.55	0.58
$\frac{15}{16}$	10	16	0.64	0.66
1	10	16	0.70	0.74
$1\frac{1}{8}$	10	16	0.79	0.83
$1\frac{1}{4}$	15	14	1.12	1.18
		12	1.44	1.52
$1\frac{3}{8}$	12	14	1.25	1.31
		12	1.60	1.68
$1\frac{1}{2}$	13	14	1.36	1.43
		12	1.76	1.85
$1\frac{5}{8}$	12	14	1.48	1.56
		12	1.92	2 02
$1\frac{3}{4}$	13	14	1.61	1.69
		12	2.07	2.18
$1\frac{13}{16}$	13	14	1.66	1.75
		12	2.15	2.26
$1\frac{7}{8}$	12	14	1.72	1.81
		12	2.23	2.35
$1\frac{15}{16}$	12	14	1.78	1.87
		12	2.31	2.43
2	15	14	1.84	1.94
		12	2.39	2.51

Outside diameter. Inches.	Length. Feet.	Thickness. Stub's W. G.	Weight per foot. Pounds. *Brass.*	*Copper.*
$2\frac{1}{8}$	13	14	1.97	2.07
		12	2.55	2.68
$2\frac{1}{4}$	14	14	2.08	2.19
		12	2.71	2.85
$2\frac{3}{8}$	13	14	2.20	2.32
		12	2.86	3.01
$2\frac{1}{2}$	13	13	2.65	2.79
		11	3.31	3.48
$2\frac{5}{8}$	12	13	2.78	2.93
		11	3.49	3.67
$2\frac{3}{4}$	12	13	2.93	3.08
		11	3.66	3.85
3	12	13	3.20	3.37
		11	4.01	4.22
$3\frac{1}{8}$	10	13	3.34	3.51
		11	4.18	4.40
$3\frac{1}{4}$	10	13	3.48	3.66
		11	4.35	4.58
$3\frac{1}{2}$	10	13	3.75	3.95
		11	4.70	4.95
4	10	13	4.30	4.53
		11	5.40	5.68
5	10	12	6.18	6.50
		10	7.56	7.96
6	10	12	7.44	7.83
		10	9.11	9.59

These tubes are polished, both inside and outside. They are perfectly cylindrical on the outside; the bore is a gradual taper, the difference in diameter being two wire-gauges in eleven feet.

TABLE XXXVI.

STUB'S WIRE-GAUGE.

Stub's wire-gauge.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Fractions of an inch. .	$\frac{19}{64}$ *f*	$\frac{9}{32}$ *f*	$\frac{1}{4}$ *f*	$\frac{15}{64}$ *f*	$\frac{7}{32}$ *f*	$\frac{13}{64}$	$\frac{3}{16}$ *b*	$\frac{11}{64}$ *b*	$\frac{9}{64}$ *f*	$\frac{9}{64}$ *b*	$\frac{1}{8}$ *b*	$\frac{7}{64}$	$\frac{3}{32}$ *f*	$\frac{5}{64}$ *f*	$\frac{5}{64}$ *b*	$\frac{1}{16}$ *f*	$\frac{1}{16}$ *b*	$\frac{3}{64}$ *f*	$\frac{3}{64}$ *b*	$\frac{1}{32}$ *f*

NOTE.—*f* means *full*; *b* means *bare*.

6. Methods of expanding Tubes.—The tubes are generally secured in the tube-sheets by expanding their ends by means of a special tool, which forces the metal of the tubes into close contact with the circumference of the holes in the tube-plates, and in some cases forms a shoulder on the tubes inside and outside the tube-plates. Sometimes a ferrule is driven tightly into the tube, and the projecting end of this ferrule may be riveted over the end of the tube. These ferrules add much to the tightness and holding power of the tubes in the plates, but contract the opening for draught and interfere with the sweeping of fire-tubes. The ends of the tubes are annealed before undergoing the process of expansion. It is of great importance that the joints between the tubes and the tube-plates shall be made perfectly tight, not only to prevent leakage with its attendant evils, but also to make the tubes act as efficient stays for the tube-plates. On the other hand, when the tube-plates are kept too rigidly in position, and cannot yield in obedience to the expansion of the tubes in the direction of their length with an increase of temperature, the tubes must have a chance to bend sidewise, which action will take place when the length of the tubes is so great in proportion to their diameter that they sag down. The thickness of the tube-plates must be sufficient to afford a good bearing to the tubes for making the joint, and to ensure proper stiffness in the plates after the numerous large holes are drilled. They are generally made at least $\frac{1}{2}$ inch thick.

The centres of the holes being marked on the tube-sheets, a small hole may be punched to serve as a guide for the drill, and the tube-holes are then drilled accurately circular and cylindrical to such a size that the tubes can be just passed through by hand; if the holes be too large the ends of the tubes might have to be expanded so much that they might crack or be strained, causing them to split afterward. The hole,

after being drilled, is often slightly counterbored at the outer face of the sheet; the edge of the hole is then smoothed with a file to remove burrs and inequalities, which would prevent contact all around and dent or cut the tube-end. The tube, which is a quarter of an inch longer than the distance between the outer faces of the two sheets, is then put in place so that each end protrudes one-half of that amount; the expanding-tool being then inserted at the end, the tube is expanded, sometimes inside and outside the tube-plate, and sometimes riveted over slightly on the outside into the counterbore. Sometimes the tube-holes are bored slightly conical for the purpose of increasing the holding power of the tubes (see Plates XXIII., XXIV.)

Figure 128 represents *Raymond's patent recessed tube-sheet.* The tube-sheet is made very thick to give it great stiffness, and the tube-holes are countersunk, so that the tube-ends may be turned over within the recess. In this manner the tube-ends in the combustion-chamber are less exposed to the impingement of the products of combustion, which causes them to wear rapidly, thus destroying their tightness and holding power. For further protection the recess may be filled with cement.

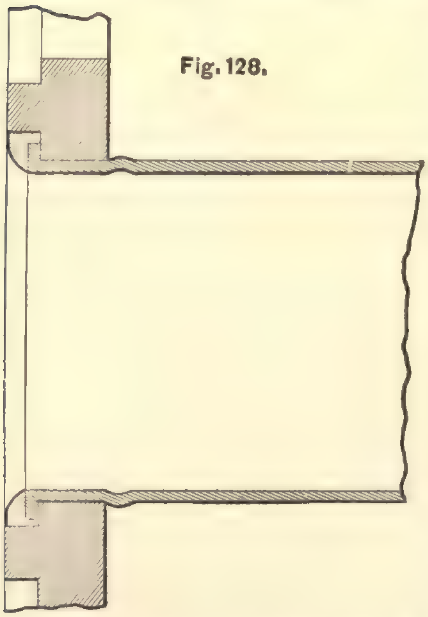


Fig. 128.

Prosser's expanding-tool is shown on Plate XXIII., and acts by percussion. It consists of a circular die formed by several truncated sectors, held together loosely by a ring, which, however, is large enough to permit them to be driven asunder by a slightly conical mandrel forced between them; the dies are provided with two rounded shoulders, one of which, when the mandrel is driven, enlarges the portion of the tube within, and the other that without, the plate. The mandrel being backed out by tapping it on the side or through the other end of the tube, the sectors are released and turned somewhat and the mandrel driven in again, so as to subject all portions of the tube-end to their action.

Dudgeon's tube-expander (see Plate XXIII.) was invented 1867, and is very extensively used. It consists of a hollow cylinder of less diameter than the tube, and provided with openings to receive three or more steel rollers, which rest inside upon a central conical mandrel. A guide-sleeve, which bears against the tube-sheet, is secured to the hollow cylinder by a set-screw. By shifting the position of this sleeve the expander is made to answer for any thickness of tube-sheet. By inserting the tool into

the tube and pressing upon and revolving the mandrel the rollers are set in motion, and, travelling around the circumference of the tube, press out the metal of the tube-end gradually. After the metal of the tube has completely filled the hole it is compressed in the wake of the tube-sheet, but it yields on each side of it, forming shoulders there; this action is shown exaggerated in figure 129.

Fig. 129.

These expanders are made of different sizes to fit any size of tube between the limits of one inch and seven inches external diameter of tube.

Fig. 130.

Sometimes the rollers are shaped as in figure 130; this form, it is claimed, strains the metal of the tube less than the straight rollers.

In still another tool the rollers are made conical, with the same angle as the mandrel, but placed in an opposite direction, so as to set the tube out exactly parallel to its axis.

Tweddell's hydraulic tube-expander, represented in figure 6, Plate XXII., is said to be very efficient and rapid in its action. The water is pumped in at A directly from a small hand-pump, and forces outward the ram B, which draws the hexagonal wedge C through the dies D, thus expanding the tube in the hole in the tube-plate E. Upwards of sixty tube-ends an hour, it is said, can be finished by this tool, using a pressure of from $1\frac{1}{2}$ to $1\frac{3}{4}$ tons on the square inch.

After the tube has been expanded the ends are often riveted over by the *boot-tool*, sketched in figure 131, or, in large and accessible tubes, they may be hammered out with a round-headed coppersmith's hammer, drawn in figure 132. It is objected to these operations that the end of the tube becomes thereby a brittle ring, which is burned off by the action of the fire, especially in the back-connection; such a result, however, indicates rather that the tube-ends were not sufficiently annealed, or that the operation had been overdone or unskilfully done. The operation of beading should not be commenced till all the tubes are fixed in place and expanded, since the stiffness of the tube-plate is greatly increased in this manner, and the blows of the hammer jar the plate less.

Fig. 131.

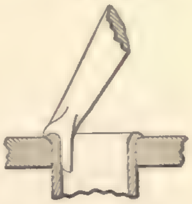
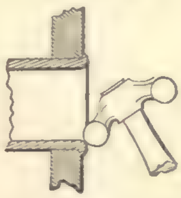


Fig. 132.



The beading of tube-ends is done rapidly and smoothly by *Selkirk's tube-beader*, illustrated in figure 7, Plate XXII. It is worked by means of a ratchet, which enables the operator to work in very confined spaces. The beading is done by rolling over the tube-ends against the tube-plate gradually with an increasing pressure; this method

obviates the danger of splitting the tube-ends, jarring severely the expanded tubes, and indenting the tube-plate by blows with the hammer, so common under the system of hand-beading in ordinary use. The action of the tool is described in *Engineering*, June, 1877, as follows: "The fixing-piece *a* is first secured firmly in the boiler-tube *b* by the action of the nut *c*, which draws the coned mandrel *d* outwards, thrusting the serrated wedge-pieces *e* (three in number) outward against the tube *b*. The body-piece *f* is then brought into position, so that the beading-rollers (three in number) bear upon the edge of the tube at *b′*. A considerable pressure is then brought to bear upon the beading-rollers by the action of the nut *h*, friction-rollers, *i*, being placed between the nut *h* and the body-piece *f* in order to avoid all unnecessary labor. The body-piece *f* is then made to revolve upon the fixing-piece *a* by means of a ratchet-wheel, *k*, and pawl, *l*; the body-piece carries with it the beading-rollers *g*, and a very perfect bead is thus formed quickly upon the end of the tube as shown at *b′*."

In using the expanding-tools great care must be exercised not to carry the operation farther than necessary to secure tightness. The process of expanding by means of the Prosser tool, when carried too far, strains the metal severely and may cause the tube-ends to split. The Dudgeon tool becomes a dangerous instrument in the hands of an inexperienced or careless person, since the operation of rolling out the metal may be continued till the tube-ends are entirely cut off without giving warning. To prevent this the taper mandrel often carries a loose collar, which may be secured in any position by means of a set-screw, and thus limit the distance which the mandrel may enter the tool and force out the rollers.

In securing boiler-tubes it should be taken into consideration in which direction the pressure tends to force the tube-sheets; thus, in the vertical water-tube boiler, the tendency being to force the tube-sheets together, it would seem that the Prosser expanding-tool, which forms a shoulder within the sheet, would be the preferable one to be used; but in the fire-tube boiler the steam exercises pressure tending to force the tube-sheets off the ends of the tubes, and here it is evident that riveting over the ends of the tubes increases greatly their holding power, while the offset within the sheet adds to their tightness. The holding power of expanded tubes is, however, ample without riveting their ends over, as shown by experiment.

7. Stay-tubes.—Formerly it was often thought necessary to secure the tube-plates by stay-rods, designed to take the whole strain due to the pressure on the plates; but, by reference to the experiments recorded in section 9 of this chapter, it will be seen that the simple process of expanding the ends of tubes gives them sufficient holding power to enable them to act as efficient stays for the tube-sheets.

In the boilers of U. S. S. *Nipsic*, represented on Plate XII., special stay-tubes are provided to support the tube-plates at the points where an additional strain is thrown on them by the pressure acting on the centre manhole-plate at the front tube-plate, and on the stay-dome at the back tube-plate. These stay-tubes are of brass like the other tubes, and have the same diameter and thickness, but their holding power is increased by beading over their ends after being expanded with the Dudgeon tool; for this purpose the tubes are made about one-quarter inch longer than the other tubes. Such stay-tubes are sometimes made of iron, so as to be less easily injured by burning in case the water should get low in the boiler; but to place these iron tubes among a mass of closely-spaced brass tubes seems hazardous, on account of their increased liability to corrosion.

The practice of providing special stay-tubes secured by screw-threads and nuts prevails still to a great extent in boilers where the steam-pressure exceeds 45 lbs. per square inch. In English boilers these stay-tubes are generally placed not more than 18 inches apart from centre to centre. At the front end these tubes are often secured by two nuts, one inside and one outside the tube-plate; the other end, exposed to the intense heat prevailing in the back-connection, is secured by a single nut and by screwing the tube into the tube-plate with about eleven threads to the inch. These stay-tubes are generally of the same external diameter as the other tubes, but thicker.

The boilers of the steamer *Atrato*, built by James Watt & Co. in 1872, and designed to be worked with a steam-pressure of 60 lbs. per square inch, had tube-plates $\frac{3}{4}$ inch thick, brass tubes 4 inches in diameter outside, spaced $5\frac{1}{2}$ inches from centre to centre. Each tube-sheet contained four stay-tubes, spaced $16\frac{1}{2}$ inches apart according to the following directions:

"The stay-tubes are to be screwed into the back tube-plate with a nut on the outside, and there are to be two nuts on the front end, one inside and one outside. All tubes, including stay-tubes, to be ferruled at the back end. Tubes are to be one-eighth inch larger in diameter at front end, to render it easier to draw them when they have a scale on. Back tube-plates to have tapered holes into which the tubes will be expanded. Back end of tubes to be beaded; front end need not be. Both ends may be put in with Dudgeon's tool, if advisable. Stay-tubes to be $\frac{1}{4}$ inch thick; others No. 8 B. W. G. Total number of stay-tubes, 48; of others, 432."

In the boilers of the steamer *Lord of the Isles*, represented on Plate XV., the outside diameter of the stay-tubes is 4 inches, while that of the other tubes is $3\frac{1}{2}$ inches. The stay-tubes are made $\frac{3}{8}$ inch thick, with a thread cut into the body of the tube, leaving an effective outside diameter of $3\frac{13}{16}$ inches, and an inside diameter of $3\frac{1}{4}$ inches.

8. Devices for rendering Boiler-tubes Removable.—Many devices have been tried to secure boiler-tubes in the tube-plates in such a manner as to make it possible to remove them without injuring them and to replace them easily, in order to clean their surfaces thoroughly or to make the crown-sheets of the furnaces accessible for scaling and repairs. But so far none of these devices has proved perfectly satisfactory, so that the method of securing boiler-tubes permanently by expanding their ends continues to be the almost universal practice. When tubes secured in this manner have to be removed the diameter of the expanded ends is reduced by closing them, and even then considerable force is often required to draw the tubes. The ends of iron tubes generally crack during this process, and brass tubes are so much injured about the ends that these have to be cut off and new ends have to be brazed on.

To render boiler-tubes more easily removable after scale has formed on them they are often made tapering, the outside diameter at the front end being sometimes $\frac{1}{8}$ inch larger than at the back end.

The following method is said to have been successfully used in France with iron tubes: A short piece of tube made of very soft iron, and having the fibres running circumferentially instead of longitudinally, is welded to the ends of the boiler-tubes; these are secured in the tube-plates by expanding them and turning over slightly the extreme projecting ends. When a tube is to be removed the ends are grasped and closed by suitable nippers; this, it is said, can be done without injuring the tube-ends permanently, on account of their peculiar structure.

Figure 1, Plate XXII., represents a removable tube used in some boilers built at the West Point Foundry, Cold Spring, N. Y., in 1878. The tubes are 4 inches in diameter and 13 feet long; the ends of the tubes are thickened by brazing or welding upon them a coned ring; the largest diameter at the back end is made a little smaller than the smallest diameter at the front end. The tubes are driven tightly into the holes of the tube-plate and slightly expanded. The tube-plates are one inch thick, and were turned down at the rim to a thickness of $\frac{1}{2}$ inch to turn the flange. The holes for the tubes were punched, and reamed in place after the tube-plates were riveted to the shell. The tube-plates are tied together by braces of $1\frac{1}{2}$-inch round iron, secured by nuts and placed about 18 inches apart. The boilers were tested with cold water, and found to be tight under a pressure of 135 pounds per square inch. These tubes are known as *Paucksch's* boiler-tubes, and have been used to some extent in England and France.

Figures 2, 3, 4, Plate XXII., represent methods of securing removable tubes used in the French navy, and known there respectively as the *Système Infernet et Gouttes* (figure 2), *Système Toscer* (figure 3), and *Système Langlois* (figure 4). In the latter

the front end of the tubes is packed by a leaden washer, a small gutter being cut in both collar and plate, into which the lead is squeezed by screwing up the tubes; a brass collar is brazed to the end and notched for the purpose of applying the wrench. To prevent the adhesion of the tubes by rusting the threads are smeared with zinc cement, and it has been found that tubes can be taken out without much difficulty after having been in use two years. The back end is fixed by means of a slightly conical steel or iron ferrule, tightened by means of an expanding-tool. It is claimed that a tube can be removed in five minutes.

Figure 5, Plate XXII., represents a method of fixing removable tubes which was tried some years ago in high-pressure boilers of United States naval vessels, but proved unsuccessful. The bushings which secure the brass tubes in the tube-plates were made of composition metal; those at the back end of the tubes were soon burnt by the intense heat prevailing in the back-connection, and even those at the front end, which were not injured by heat, could not be unscrewed after the boilers had been in use a short time, but were twisted off in the attempt. Similar devices have been tried in English boilers with equally unsatisfactory results.

9. Experiments on the Holding Power of Boiler-tubes secured by various Methods.—In January, 1877, a series of experiments were made at the Navy-Yard, Washington, D. C., under the direction of Chief Engineer William H. Shock, U.S.N., on the holding power of boiler-tubes fixed by various methods employed in marine and locomotive engineering. Each tube subjected to trial had its ends fixed in square pieces of plate resembling portions of tube-plates. The pull was applied to stirrups attached by nuts to cross-heads which bore against the plates (see Plate XXV.) The cross-heads were made in halves and with a circular opening in the centre, in order to enclose the tube and allow the pull to be applied exactly in the direction of the axis of the tube. Plates XXIII., XXIV. illustrate fully the methods of fastening the tubes and the appearance of the specimens after the trial, and contain a complete tabulated record of the results of these experiments. The Rodman testing-machine was used in making these experiments.

Plate XXIII. exhibits the results of forty-eight experiments made with brass tubes having an external diameter of 2.5 inches and 2.6 inches, and an area of metal in cross-section of 0.9 and 1.33 square inches respectively. The tube-plates were of iron, and varied in thickness from $\frac{3}{8}$ inch to $\frac{3}{4}$ inch. Both the Prosser and the Dudgeon tool were used in expanding the tubes; the effects of beading over the ends and of driving ferrules into the tube-ends were tested under different conditions.

A comparison of the results obtained with tubes No. 5 and No. 6 shows that the

partial turning-over of the ends of the tube effected by the Prosser expander does not give such a firm hold of the tube-plate as the beading-over by hand in connection with the action of the Dudgeon roller-expander. The tubes secured by simple expansion gave way by being drawn through the plates, while the ends which were beaded over generally broke.

The effect of ferrules in increasing the holding power of tubes is very marked; they prevent the ends from collapsing and being drawn through the plates.

The tubes secured by nuts only, screwed on the outside of the plates, gave way by drawing the ends through the nuts without stripping or otherwise injuring the thread. When iron ferrules were used in connection with the nuts the holding power of the tubes was greatly increased. In experiments Nos. 15 and 16 the tubes gave way by tearing through the thread; but in experiments Nos. 19 and 20 the tubes drew from the nuts without breaking, like the unferruled tubes.

The lowest results were obtained in experiments Nos. 21 and 22, when the tubes were simply expanded by the Dudgeon tool in a $\frac{3}{4}$-inch plate, without being beaded over or secured by ferrules, the resistance being 7,650 lbs. and 5,850 lbs. respectively. It will be seen that even in this most unfavorable case the holding power of the tube was greatly in excess of any strain which would be occasioned by the pressure of steam upon the portion of the tube-plate which any one tube would have to support in a boiler.

The following general conclusions drawn from the results of these trials are quoted from an article in *Engineering*, Sept. 14, 1877, where an account of these experiments was first published—viz.: "(1) That tubes fixed by the Dudgeon expander and beaded over have a considerably stronger hold of the tube-plates than those fixed by the Prosser expander, particularly with thin tube-plates; (2) that if the tubes are not beaded over the hold afforded by the Dudgeon is less than that afforded by the Prosser system of fixing; (3) that with both expanders the introduction of ferrules adds very materially to the holding power of the tubes; (4) that, on the whole, the effect of ferrules is with the Dudgeon expander proportionately greater in thick than in thin tube-plates, while in the case of the Prosser expander the proportionate increase of resistance afforded by the introduction of ferrules is not materially affected by the thickness of the tube-plates; (5) that iron ferrules are more efficient than those of brass; and (6) that the employment of nuts screwed on the tubes outside the tube-plates is not of any service in increasing the holding power unless the tubes are ferruled."

Plate XXIV. exhibits eighteen experiments made with iron tubes secured in iron, steel, and copper tube-plates by various methods obtaining in locomotive engineering.

Dudgeon's tool is used in all cases in expanding these tubes. The outside diameter of the tubes is 2$\frac{5}{8}$ inches, but their lower end is in every case reduced by swaging to 2$\frac{3}{8}$ inches, and is fixed in a copper or steel plate, respectively $\frac{5}{8}$ inch and $\frac{3}{8}$ inch thick; the upper end is fixed in every case in an iron plate $\frac{7}{16}$ inch thick.

In experiments No. 1 to No. 8 the ends of the expanded tubes were beaded or riveted over, and in every case fracture took place by breaking the riveted end off the tube, except in experiment No. 8, when the riveted end was cracked but not completely detached from the tube, and was pulled through the plate. This took place also in experiments Nos. 9 and 10, where the ends were only partly riveted over. It is important to notice that in experiments Nos. 5, 6, 7, and 8, where the lower tube-plate was of copper, as well as in experiments Nos. 1 and 2, where at the lower end a thin copper ring was inserted between the tube and the steel plate, the fracture took place invariably at the upper end; while in experiments Nos. 3 and 4, identical with experiments Nos. 1 and 2 with the omission of the copper ring, fracture took place once at the upper end, fixed in an iron plate, and once at the lower end, fixed in a steel plate.

The great difference in the strain under which tube-ends fixed in precisely the same manner gave way indicates that the method of riveting over iron tubes is apt to injure the metal, although for these experiments all the tubes were carefully fixed by the same experienced workman. The strains at which rupture took place in the first ten experiments ranged from 29,050 in tube No. 1 to 17,300 lbs. in tube No. 6; the mean breaking strain for these ten tubes was 22,837.5 lbs.

In experiments No. 11 to No. 18 the tube-ends were not riveted over, and the tubes gave way invariably at the lower end, showing that their holding power was decreased by diminishing their diameter and the thickness of the tube-plates; experiments Nos. 8, 9, and 10 indicate, on the contrary, that when the ends are riveted over the holding power of the tube is not influenced perceptibly by a slight decrease in the thickness of the plate and in the diameter of the tube.

Comparing experiments Nos. 11 and 12 with Nos. 13 and 14, it will be noticed that the holding power of the tubes is more than doubled by the insertion of ferrules. Experiments Nos. 13 and 14 show also that iron tubes, simply expanded by Dudgeon's process, possess more than sufficient holding power to bear any strain which may be thrown on the tube-plates by the steam-pressures used in locomotive boilers.

In experiments Nos. 15, 16, 17, and 18 the holes were made tapering. In the former two experiments the larger diameter of the holes was $\frac{1}{16}$ inch greater than the smaller diameter, and the results show a remarkable decrease in the holding power of the tubes from that of the tubes Nos. 13 and 14, with simply expanded ends in cylindrical holes.

In experiments Nos. 17 and 18 the larger diameter of the taper holes was $\frac{3}{16}$ inch greater than the smaller diameter, and with these proportions the holding power was greatly increased.

10. Sectional or Water-tube Boilers, Hanging Tubes, Double Tubes, etc.—Since a number of years the so-called sectional or water-tube boilers have come into great favor as stationary boilers for various purposes, and many devices relating to this class of steam-generators, and presenting more or less novelty, have been patented and introduced into the market. In general these boilers consist of an assemblage of tubes connected with one another by means of elbows or branch-pipes, and placed in vertical and horizontal tiers, over and surrounding a grate, and enclosed by walls built of fire-brick or constructed of some other non-conducting material; in some arrangements the tubes are bent into a coil or into a siphon-shape.

The principal advantages claimed for this class of boilers are the following: (1) The small diameter of the tubes of which they are composed, and the absence of riveted joints, render them much stronger than the ordinary rectangular or cylindrical boilers. (2) They are safer; for even in case some tubes burst no violent explosion ensues, because the fractured parts present a relatively small opening, and the quantity of water and steam contained in these boilers is small in proportion to their power. (3) They can be cheaply built, and repaired with great facility, duplicate pieces being easily kept in store for this purpose; the separate parts of a boiler can be transported long distances without great expense or inconvenience; the form and proportions of a boiler are easily altered or adapted to any available space, and the power of a boiler is increased by simply adding new tiers of tubes and grate-surface. (4) Their evaporative efficiency can be made equal to that of other boilers, and, in fact, for equal proportions of heating-surface and grate-surface, it is often somewhat higher.

With two or three exceptions all attempts made so far to adapt these boilers for use on board of vessels have resulted unsuccessfully, and in several instances disastrously. While in some instances these failures could be traced to avoidable mistakes in the design of the boilers, there are several reasons why tubulous boilers are not well adapted for marine purposes, unless radical changes should be introduced in the present practice of marine engineering.

(1) These tubulous boilers occupy as much valuable space as the ordinary types of marine boilers.

(2) On account of the small quantity of water carried in them any irregularities in the supply of feed-water or in the management of the fires cause sudden fluctuations of pressure, and a sudden, rapid generation of steam leads to an accumulation of steam in

the water-chambers, and to priming, loss of water, and overheated tubes; these troubles can be much more easily avoided with regularly and continuously working factory engines than with marine engines, which have often to be operated in an intermittent manner in getting under way and in coming to a wharf or to an anchorage.

(3) The horizontal or inclined water-tubes, of which these sectional boilers are mainly composed, do not present a ready outlet for the generated steam. The steam-bubbles, instead of being able to follow their natural tendency and rise, have generally to travel in a horizontal direction the whole length of the tubes, and this they will not do without being urged by an extraneous force. There exists, consequently, a liability for steam to accumulate in the water-tubes and cause them to be burnt; and this liability is generally greater in the case of marine boilers, where economy of space demands a rapid combustion and evaporation, than in stationary boilers, where economy of fuel is sought for by slow combustion and evaporation.

(4) This liability to overheating of the tubes is still increased by the use of water which forms deposits of solid matter on the heating-surfaces of boilers. The surface-condensers of marine engines are seldom so perfectly tight as to keep the boilers fully supplied with distilled water for any length of time; and, besides, it is a well-established fact that with marine boilers the choice lies between the formation of a slight deposit of scale and rapid corrosion.

Some inventors have relied upon the scouring action of the water circulating rapidly through the tubes of their boilers as a means of preventing the deposit of scale; others thought that the expansion of the heated tubes would detach each thin deposit of scale, and thus prevent it from accumulating to a dangerous extent. But these speculations have not been realized in practice. Besides, in boilers of naval vessels, which are often kept for many days in succession under banked fires, the circulation of the water is during such time necessarily sluggish.

In *Perkins's tubulous boiler*, which, on a small scale, has been successfully applied in two or three instances to marine purposes, distilled water, as nearly as possible chemically pure, is used. All joints of the boiler are made perfectly tight. A surface-condenser and stuffing-boxes of peculiar design are used for the engines, in order to avoid all loss of steam; no lubricant is used for the valves or pistons; the whistle, the blast, and the steam-pumps are supplied with steam by an auxiliary boiler; in this manner it is made possible to use the same pure water over and over again. A quantity of fresh water carried in tanks, and a distiller, are provided to replace any water accidentally lost.

The boiler illustrated in figure 1, Plate XXVI., is described by the inventor,

L. Perkins, in a lecture delivered before the Royal United Service Institute, 1877, as follows:

"The horizontal tubes are $2\frac{1}{4}$ inches internal and 3 inches external diameter, excepting the steam-collecting tube, which is 4 inches internal and $5\frac{1}{2}$ inches external diameter. The horizontal tubes, being welded up at each end one-half inch thick, are connected by small vertical tubes $\frac{7}{8}$ inch internal and $1\frac{5}{16}$ inches external diameter. The fire-box is formed of tubes bent into a rectangular shape, placed at a distance of $1\frac{3}{4}$ inches apart, and connected by numerous small vertical tubes. The body of the boiler is made of a number of vertical sections composed each of eleven tubes, connected at either end by a vertical tube; these sections are connected at both ends by a vertical tube to the top ring of the fire-box, and by another to the steam-collecting tube. The whole of the boiler is surrounded by a double casing of thin sheet-iron, filled up with vegetable black to avoid loss of heat. Every tube is separately proved by hydraulic pressure to 4,000 lbs. on the square inch, and the boiler complete to 2,000 lbs., this pressure remaining on for some hours." The connecting-tubes are screwed into the main tubes, and the threads are then calked down to make the joint perfectly tight.

Some boilers of this description have been used on land for thirteen years, with pressures varying from 250 to 300 lbs., and tubes, cut out for examination at the end of that period, have been found to be clean and to show no signs of corrosion, owing partly to the rigorous use of distilled fresh water, and partly, it is supposed, to the formation of the black oxide of iron by the contact of superheated steam with the highly-heated surfaces. It is stated that steam is formed even in the lowest tubes; that water exists in the form of spray in the middle portion of the boiler, and that the upper tubes contain dry steam; and that the safety of the tubes is ensured by the great density of the steam, which increases greatly its power of conducting heat. These boilers have generally been operated with a low rate of combustion, while, at the same time, the ratio of heating-surface to grate-surface is large.

Figure 1, Plate XXVI., represents one of the four boilers of the steam-yacht *Wanderer*. Each boiler contains 19 square feet of grate-surface and 760 square feet of heating-surface; the working pressure is 400 lbs. per square inch. The total weight of the four boilers, including water, is about 34 tons. It is claimed that the *Wanderer's* engines developed, with 92 revolutions per minute, a maximum of 907 horse-powers. In other vessels, having boilers of identical design and dimensions, a performance of 150 horse-powers per boiler was obtained.

Figure 2, Plate XXVI., represents a *Howard water-tube boiler* designed for marine purposes. The tubes forming each vertical tier communicate with each other at one

end by a stand-pipe, and near the other end, which is closed, by short corrugated connecting-tubes. The closed ends are provided with mudhole-doors. The feed-water enters a horizontal tube at the back of the boiler, connected by short branches to the vertical stand-pipes. A cylindrical steam-drum runs across the top of the boiler, being connected to the top tube of each vertical tier.

The *Belleville* water-tube boilers have attracted much attention in France, and a great number of them were built some years ago for the French navy. Various modifications have been introduced in these boilers from time to time. Figure 2, Plate XXVII., represents a boiler of this class built for the despatch-vessel *L'Active*, of the French navy, in 1868. There were three of these boilers, supplying steam to compound engines of 400 indicated horse-powers.

The following information regarding them is derived from *Engineering*, March 4, 1870:

Each steam-generator proper consists of eleven "*elements*," each composed of twelve tubes, disposed one above the other and coupled at their alternate ends by connecting-boxes. The eleven elements are placed side by side at a short distance apart. A transverse tube, B, connects all the lower tubes and serves to distribute the feed-water to the various elements. The upper tubes are all connected with a transverse steam-collecting tube, C, parallel to which is placed the round pipe D, which serves to lead the steam off to the engines. The pipes C and D are connected by five vertical pipes of different sizes, for the purpose of equalizing the draught of steam from the various sections. The tubes are of wrought-iron, lap-welded; the connecting-boxes into which the tubes are screwed are of malleable cast-iron, and each is furnished with a couple of mudholes opposite the ends of the tubes. All the elements are connected together at the front by the upper and lower connecting-tubes, and at the back by a wrought-iron frame and tie-bolts, distance-pieces being provided to maintain the proper intervals between the elements; in this manner the tubes are left free to expand or contract longitudinally. The tubes are each formed in a single piece, except the upper and lower tubes of each element, which are each made in two pieces, connected by a coupling, for the purpose of facilitating the putting together and taking to pieces of the elements. The whole of the boiler proper is enclosed in a casing composed of wrought-iron plates and angle-irons, lined with fire-bricks. A number of plates are placed in the upper part of the boiler to deflect the current of the gases. The feed is regulated by a self-acting, adjustable float placed in the vertical wrought-iron cylinder in front of the boiler, to which also the gauge-cocks are attached. A "*separator*," placed between the boilers and the engines, frees the steam of the water and other foreign matter held in suspension. The principal dimensions of the boilers of *L'Active* are as follows:

Number of boilers	3.
Height of boilers	7 feet 7 inches
Length of boilers	8 feet ½ inch.
Width across three boilers	14 feet 8 inches.
Total number of tubes	396.
Interior diameter of tubes	2¾ inches.
Thickness of tubes	0.24 inch.
Length of tubes	6 feet 10⅝ inches.
Total grate-surface	75.34 square feet.
Total heating-surface	2,347 square feet.
Load on safety-valves	113 lbs. per square inch.

Figure 1, Plate XXVII., represents the *Herreshoff coil-boiler* of the steam-yacht *Estelle.*

The following data are derived from the report of the Board of Naval Engineers, who conducted a trial with this vessel in December, 1877:

This boiler consists of a single circular grate, 7 feet in diameter, surrounded by a fire-brick wall 18 inches in height above the top of the grate-bars and 7 inches in thickness. Upon the top of this brick wall there rests a single coil of continuous wrought-iron pipe, which contains the steam and water, while its outside is exposed to the hot gases of combustion. The outline of this coil, considered as a whole, is composed of the frustums of two right cones, one superimposed upon the other. The lower frustum is 7 feet in inner diameter at the base and 6 feet in inner diameter at the top, with a vertical height of 7 feet and 4 inches. The upper frustum is 6 feet in inner diameter at the base and 1 foot and 11 inches in inner diameter at the top, with a vertical height of 10½ inches. The spirals of the lower frustum are kept apart ¾ inch by stirrup-bolts. The spirals in the upper frustum touch, and the entire top is covered with sheet-iron; thus all the gases are compelled to pass between the openings between the spirals of the lower frustum. The coil makes a total of thirty turns, all of which are continuous, without a single joint, being made by welding together the ends of the several sections of pipe composing the coil. Starting from the bottom, the pipes forming the coil gradually decrease in size, the lowest section being 4½ inches in outside diameter and 0.119 inch in thickness, and the uppermost section being 1½ inches in outside diameter and 0.069 inch in thickness. The coil is surrounded by a hollow cylindrical casing, 8 feet 3 inches in outside diameter, filled with fire-brick 1½ inches thick.

The feed-water enters the coil at the extreme top, and, flowing slowly down the

spirals, becomes converted into steam. From the lower end of the coil a straight wrought-iron pipe, 4½ inches in outside diameter, passing up on the coil directly over the grate, leads the steam to the "*separator*," a cylindrical vessel located outside the boiler, where the water and other impurities mingled with the steam are deposited. The steam is drawn off at the top of the separator, and passes through a coil of pipe within the uptake of the boiler, where it is superheated before it enters the engines. It is essential that a portion of the feed-water should pass in the form of spray with the steam into the separator, in order to prevent the overheating of the lower coils of the tube. In the older boilers of this type, in which sea-water was used, this surplus of water entered the separator as highly-concentrated brine, and was blown off. In later boilers, where fresh water is used, this water is either blown into the condenser or is directly fed back into the boiler by a special pump. The quantity of water which passes thus into the separator is about 25 per cent of the quantity evaporated.

The following are the principal dimensions and proportions of the boiler illustrated on Plate XXVII.:

Diameter of the boiler to outside of casing	8 ft. 3 ins.
Height of the boiler from bottom of ashpit to top of coil	11 ft. 3 ins.
Area of grate-surface	38.4846 sq. ft.
Total area of heating-surface, measured on the outside of the pipe	511.184 sq. ft.
Length of the axis of the coil	539.550 ft.
Capacity of the coil	34.488 cub. ft.
Ratio of heating-surface to grate-surface	13.283 to 1.
Weight of brick-work in the boiler (calculated)	7,250 lbs.
Weight of iron in the boiler (calculated)	9,250 lbs.
Total weight of boiler, including brick-work, grate-bars, ashpit, uptake, separator, casing, coil, etc.	16,500 lbs.
Weight of water in coil and separator, allowing the coil to be half-filled	1,100 lbs.

Steam was raised with wood from water at the temperature of 44° Fahr. in sufficient quantity to start the motive-engine, and maintain it in motion, in seven minutes from the lighting of the fire. The feeding has to commence a few moments before the fires are lighted.

During the trial, which lasted eight hours, the extreme variations of boiler-pressure were between 65 and 75 lbs. per square inch. This uniformity of pressure is ascribed to be due to the use of artificial draught by means of a fan-blower, and to the uniform working of the engine.

During a short full-power trial, lasting fifteen minutes, the engine developed 293.28 indicated horse-powers, with a steam-pressure of 106.5 lbs. in the boiler.

The interior of the pipe is, of course, utterly inaccessible for scaling or examination. The use of the boiler is limited to fresh water, supplied by tanks or surface-condensers. When sea-water is used the coil gradually scales up, commencing at the lower end of the coil.

The lightness of the boiler is dependent to a great extent upon the small amount of heating-surface and to the thin walls of the fire-brick casing; but, even after increasing the former to the amount usual in marine boilers, the weight of the Herreshoff boiler would be only about one-half of the weight of the ordinary marine boiler.

Many novel devices in the arrangement and form of the tubes of vertical boilers have been introduced of late, with a view to combining lightness and compactness and rapid circulation of the water in every part of the boiler with high potential and economic evaporative efficiency.

The *Davey-Paxman boiler*, illustrated in figure 2, Plate XXVIII., is highly recommended in these respects. The merits of this boiler are due to the bent and tapering water-tubes and to the deflector inserted in the top of each tube. The water in these tubes, being exposed to the full heat of the furnace, soon acquires a high temperature, and as it rises rapidly it is replaced by solid water flowing in at the lower end. So great is the velocity of the water through these tubes that it rises in jets up to the crown-plate, unless arrested by the deflectors, which divert these water-jets downward and keep the water perfectly smooth on the surface. This rapid circulation of the water allows no incrustation to take place in the tubes.

In many cases boilers are fitted with so-called "*hanging-tubes*." These tubes hang vertically over the fire, being closed at the bottom by means of a plug or by welding, and being secured at the upper end in the tube-plate which forms the crown-plate of a very high furnace. A tube of smaller diameter leads down into the larger tube, leaving an annular space through which the steam ascends, while solid water flows down through the inner tube. The top of the latter extends a short distance above the outer tube, but the lower end does not reach quite to the bottom of the outer tube, in order to leave room for the passage of the water. The success of this arrangement depends on the complete separation of the ascending and descending currents in the tubes. The outer tubes are sometimes fitted at the top with deflecting arrangements of various forms. These hanging-tubes are principally used in the boilers of fire-engines, road-engines, etc.

CHAPTER XII.

UPTAKE, CHIMNEY, STEAM-JETS, FAN-BLOWERS, ETC.

1. Smoke-connections and Uptake.—The gases of combustion are discharged by the tubes or flues into chambers called the smoke-connections, or, in the return-tube boiler, the front-connections, which gradually converge to a common passage, called the uptake, leading to the base of the chimney. The smoke-connections and uptake are either built permanently within the shell of the boiler, forming an integral part of the latter and being partly surrounded by water and steam-spaces, or they consist of a separate box, constructed of angle-irons and plate-iron, and secured to the outside of the shell of the boiler. In the former case the uptake may be so arranged as to present valuable heating-surface for drying and superheating the steam; this subject will be considered in chapter xiii. When the front-connections and uptake are built separately they form, with their linings, a considerable part of the total weight of the boilers; they increase greatly the temperature of the fire-room by radiation, unless they are well protected by non-conductive materials; and they give frequently trouble by warping when the gases of combustion are discharged at a high temperature.

The smoke-connections must not only form a sufficiently large and unobstructed passage for the gases of combustion, but must allow easy access to be had to the tubes for sweeping, replacing, or calking them; for this purpose they are provided with large hinged doors. The cross-area of the front-connections increases gradually from the bottom to the top and from the ends of the boiler to the place where they merge in the uptake, so as to preserve a uniform ratio of cross-area to the bulk of the gases discharged into them by each additional row of tubes. All sudden enlargements should be avoided as much as possible; all bends should be made with easy curves, and the irregular form of the uptake should change gradually into the regular figure representing the cross-section of the smoke-pipe. When several currents of a fluid, moving in different directions, meet in a common passage they retard each other, and, under certain conditions, the one moving with the greatest speed may even obliterate entirely

the other currents. This well-known phenomenon is too often lost sight of in the construction of the uptakes of boilers, and the draught of boilers may be seriously injured in consequence. The current of gases issuing from one set of flues should never cross the direction of other currents on entering the same passage, but partitions should be provided which keep the currents separate till they have assumed the same direction.

In rectangular boilers of the return-tube type the front smoke-connections and the uptake are generally built permanently in the boiler (see Plates VI., VII., XVII.) In this case the front tube-plates are set back a short distance from the front of the boiler, and the latter is made to slope outward from the bottom of the front-connection upward, in order to get more room at the top for the passage of the gases. The bottom of the connection must be placed so as to give sufficient room for expanding and calking the lower row of tubes, and for turning the flange which connects the tube-plate to the bottom plate of the connection. Room is saved between the latter and the furnace-crown by turning the flange on the tube-plate, and not on the bottom plate of the front-connection. The top of the front-connection is generally arched, not only to give it strength, but because such a form offers less resistance to the flow of the gases than a square cross-section.

The front-connections form often a clear passage extending from one end of the boiler to the other. In this case the construction of the boiler is greatly simplified by leaving the whole front of the connections open, and forming the jambs or supports for the connection-doors by bolting flat bars to the front of the boiler across this open space.

In the rectangular boilers of United States naval vessels these jambs are generally formed by columnar water-spaces (see Plates VI., VII.); they complicate the construction of this part of the boiler, but are useful as channels for the downward course of the water.

By extending these water-spaces across the front-connections, so as to form walls which separate the several nests of tubes, the weight of the boiler is slightly increased, but some additional heating-surface and freer channels for the circulation of the water are gained; and the draught of the end furnaces is improved, because the body of gases generated by each furnace is kept separate until the different currents assume the same direction on entering the uptake.

The form of the uptake depends on the arrangement of the boilers with reference to one another and to the chimney. When a single boiler is used the uptake slopes inward, so as to bring the smoke-pipe over the base of the boiler. When several boilers are placed opposite to one another the uptake slopes outward, spanning the space be-

tween the boilers; with such an arrangement each boiler contains a portion of the uptake, so that when the boilers are placed in position the sides of the overhanging uptake meet and are bolted together, forming thus a common passage (see Plates VI., VII.) In such a case it would be better to keep the uptake of each boiler separate by a partition extending to the base of the chimney. Such parts of the uptake as lie outside the shell of the boiler, and are not surrounded by steam-drums, are frequently lined with fire-brick, or are coated on the outside with some incombustible, non-conductive material to prevent the radiation of heat.

With high-pressure cylindrical boilers it is more convenient to build the boiler proper complete in itself, and to add the front-connections and uptake as separate structures; this plan simplifies the construction of the cylindrical shell and avoids the use of flat stayed surfaces. The bottom, top, and sides of the uptake and connections are generally either lined with fire-brick or are made with a double shell, which is frequently filled with some non-conductive substance, like plaster-of-Paris or a mixture of plaster-of-Paris and ashes.

The uptakes, and the fastenings which secure them to the boilers, must be strong enough to carry the weight of the smoke-pipe in addition to their own weight; and, besides, they are sometimes designed to tie the boilers together at the top. They are made to rest partly on the top of the cylindrical shell, and special provisions, in the shape of beams and stanchions, are often made to support their overhanging portions. The required strength and stiffness of the structure should be provided for by a proper arrangement of the frames, made of angle-irons, T-irons, or channel-irons. The selection of the thickness of the plate-iron must be governed by the following considerations: It must be riveted together with air-tight joints; it must not buckle under the strains or warp in consequence of the heat to which it is exposed; and it must not be destroyed too rapidly by corrosion. For double shells much thinner iron may be used than for single shells lined with fire-brick. The inner lining of double shells is made heavier than the outer lining, because it is more exposed to warping and corrosion.

In the boilers of the U. S. S. *Nipsic* (see Plates XXIX., XXX.) the front-connections of each set of boilers on the same side of the vessel form a clear passage from one extreme end to the other. They are attached to the front of the boilers by angle-irons, and to the cylindrical shells by channel-irons, secured by tap-bolts. The bottom of the front-connections is formed by a single thickness of plate riveted to the angle-iron, which extends in one continuous length along the fronts of the boilers. The other walls of the front-connections and of the uptake are double, the inner lining being made of No. 10 W. G. iron and the outer lining of No. 13 W. G. iron. The inner and

outer plates of the double shell are connected by channel-irons ($2\frac{1}{2}'' \times 2'' \times \frac{3}{8}''$), through-rivets passing through both plates and both flanges of the channel-irons. The sides of the connections and uptake are connected by angle-irons. Additional supports for the connections are provided in the shape of brackets resting on the flanges of the furnace-tubes, and in the centre under the smoke-pipe the uptake is supported by a pair of flanged beams, 12 inches deep, running in the fore-and-aft direction of the vessel. These beams are placed 20 inches apart, and are supported at either end by a wrought-iron stanchion resting on the keelson. Supports for the deck-beams over the boilers rest likewise on these beams.

The weight of the front-connections and uptake of these boilers is, according to calculation, about 10,000 lbs., and the actual weight of the plaster-of-Paris used in filling them was, in the dry state, 5,000 lbs., making the total weight of the front-connections and uptake of these boilers when filled about 16,350 lbs.

In the U. S. S. *Trenton*, having eight three-furnace boilers twelve feet in diameter, each boiler has a separate front-connection, sloping outward from a least width of 9 inches at the bottom to a uniform width of 30 inches at the top, where it is open to the uptake. The latter forms a continuous passage along the fronts of the boilers on each side of the vessel. Its cross-section is square, and its width and height increase gradually from the extreme ends to its junction with the base of the chimney. All the walls of the connections and uptake consist of a single shell, lined with fire-brick in the uptake. The side, bottom, and front plates of each front-connection are riveted to a two-inch angle-iron bent to the shape required for the outline of the box and secured to the front of the boiler, and to the square frames, made of 2-inch angle-irons, surrounding the connection-door openings. The plates forming the uptake are of $\frac{1}{4}$-inch iron, connected by 2-inch angle-irons. The uptake is fastened at the back to the cylindrical shell of each boiler by means of a 3-inch angle-iron, and the overhanging part is supported by 4-inch T-irons, two of which are placed on the top of the front-connection box of each boiler. These T-irons extend across the fire-room, and are secured at either end by a strap bolted to the front of the boiler. For the support of the smoke-pipe the central part of the uptake forms a heavy framework. The pipe rests on a square $\frac{3}{4}$-inch plate, with a circular opening corresponding to the cross-section of the smoke-pipe, and strengthened by a ring formed of 4-inch angle-iron and having an inner diameter 2 inches larger than the outside diameter of the base of the pipe. The four sides of this horizontal top plate are secured by 3-inch angle-irons to vertical plates $\frac{3}{4}$ inch thick. The vertical plates running athwartships are 12 inches deep, and those running in a fore-and-aft direction are secured to the cylindrical shells of the boilers by

3-inch angle-irons. The rest of the uptake is connected to this central portion by 2-inch angle-irons.

It is of the utmost importance that the uptake-doors be made to fit air-tight against their seats, in order to prevent the in-leakage of air, the effect of which is to decrease the draught of the chimney by lowering its temperature and increasing the bulk of gases to be passed through it in a given time.

The draught of the boiler measures, other things equal, its potential vaporization; and having constructed a boiler, every precaution should be taken to obtain from it the utmost performance by losing none of the draught due to the temperature and bulk of the gases of combustion delivered into the base of the chimney. When it is necessary to force from a boiler the utmost quantity of steam in a given time, the uptake-doors, where they meet their seat, should be luted with clay, so as to absolutely prevent the ingress of the cold external air. These remarks, of course, apply only to the cases where natural draught is employed alone or in conjunction with a steam-jet in the chimney. When the draught is produced artificially by means of blowers delivering blasts of air into closed ashpits, tight uptake-doors may still be needed to prevent the gases of combustion from being driven into the fire-room.

When the uptake-doors are so large that the labor of opening and closing them becomes serious it is frequently convenient to construct in them a much smaller door, to be opened when it is desired to check the combustion in the furnaces. This combustion may, indeed, be checked still more promptly by opening the furnace-doors, thereby allowing the inrush of a mass of cold air above the incandescent fuel and through the furnaces and tubes; but it is done at the risk of injuring the riveting by the too sudden cooling of the plates, and the radiation into the fire-room from the glowing fires is so great as to be a serious inconvenience, and sometimes an injury, to all the persons who have duties there.

2. Forms and Dimensions of Chimneys.—The chimneys of marine boilers are generally cylindrical, with a circular cross-section. Sometimes the cross-section is oval, with the greater diameter lying in the fore-and-aft direction of the vessel. This form is used to gain room on deck athwartships for clearing certain parts of the rigging. Another advantage claimed for this form—viz., that it offers less resistance to a head-wind—is practically insignificant. The flat sides of oval chimneys are stiffened by braces. A chimney of circular cross-section has not only the strongest form, requires the least weight of metal, and is most easily made, but offers the least surface for friction and radiation.

When several boilers discharge their gases into the same chimney the latter is some-

times divided by partitions running the whole length of the pipe, so that each division forms a separate chimney for each boiler. This arrangement is advantageous for war-vessels, which frequently steam with only a fraction of their boiler-power. According to Ledieu, this plan of subdividing the chimney is often adopted in the French navy, even when hoisting-pipes are used, although in such cases it complicates their construction greatly.

The effect of this division of a chimney by partitions extending from bottom to top was tested by Chief Engineer Isherwood, of the United States navy, on board the United States steam-frigate *San Jacinto*, in 1862. The tubular boilers of that vessel were two in number, placed opposite each other with the fire-room between and in common to both, the chimney being also common to both and placed over the centre of the fire-room. When only one boiler was in operation the difference in its draught was strongly marked, whether the partition was left out and the whole chimney cross-area used, or whether the partition was put in and half the chimney cross-area used; the ashpit-doors, furnace-doors, and uptake-doors of the boiler out of operation being carefully luted in the former case so as to absolutely prevent any passage of air through it.

When the draught is produced by artificial means—viz., by a steam-jet or by fan-blowers—there is a certain cross-area of chimney which gives the least resistance by friction and the best effect of the blast, while the height of the chimney need only be great enough to discharge the products of combustion without producing inconvenience. In the English torpedo-vessel *Vesuvius* the chimney consists of a horizontal duct leading aft along the sides of the vessel.

When natural draught is to be used—that is to say, when the draught is to be produced by the difference in weight of the column of hot gas within the chimney and of an equally high column of outside air—the dimensions of the chimney for a given rate of combustion may be calculated according to the rules and formulæ given in section 11, chapter ii. When natural draught is used in marine boilers the cross-area of the chimney varies from one-sixth to one-tenth of the area of the grate; and the limit of the height of the chimney of steamships is about 65 feet, measured from the level of the grate.

In war-vessels which are intended to manœuvre frequently and for long periods under sail without the use of steam-power the chimney is made telescopic, with one or two movable sections, which slide within a fixed pipe and are hoisted when the boilers are in use and lowered after the fires are hauled. The chimneys of steam-launches and similar small vessels are frequently provided with a hinge (see Plate XVI.), so that they can be let down into a horizontal position.

Chimneys must be made with air-tight joints to prevent leakage of air on account of the difference of pressure inside and outside, as such leakage injures the draught. For this reason, also, the use of telescopic chimneys is very objectionable, causing a marked decrease in the draught of the boiler, as it is impossible to make them air-tight, there being necessarily an annular space of more or less width, according to accuracy of fitting, between the standing and the sliding portions.

Telescopic chimneys are employed only on board of war-steamers, and in them only because a considerable portion of their cruising is done under sail alone. The position of the chimney being so near the mainmast as to prevent the setting of the mainsail, the inconvenience is sought to be avoided by lowering the chimney; the height of the standing portion, however, is frequently such that, even when reduced to the minimum, the mainsail cannot be set. The principal benefit derived from telescoping the chimney is to make the vessel look more like a sailing ship—an appearance extravagantly paid for in the decreased power of the boiler and consequently lessened speed of the vessel under steam-power.

If it was desirable to keep the inner surface of the chimney clean, then that surface should be made as smooth as possible, so as to offer the least resistance to the ascending gaseous currents, which would be particularly important in the case of small chimneys and rapid currents. But it is found advantageous to allow the inner surface to remain coated with the soot and tarry hydrocarbons deposited from the gases of combustion, as this coating efficiently prevents the radiation of heat from the outer surface, which it is desirable to avoid, as such radiation reduces the draught by lowering the temperature of the gases within the chimney. So long as it is the surface of this coating which is exposed to the gaseous currents, the smoothness or roughness of the surface to which the coating adheres is of but little importance. Of course the friction-resistance of the rough surface presented by the hydrocarbon coating reduces the draught more than a smooth surface of metal, and to that extent loses what it gains by its less heat-conducting power.

To regulate the draught of a boiler, and consequently its rate of combustion, a valve, called a damper, is often placed within the flues, which slides or swings across their opening, and which in stationary boilers is sometimes regulated automatically by the steam-pressure. In marine boilers the damper is frequently omitted; when used it is placed within the smoke-pipe, near its lower end, and consists of a circular plate which swings around a horizontal spindle. The latter projects outside the pipe, and is operated by hand by means of a rope or chain attached to a wheel or crank fixed to the spindle.

3. Fixed Chimneys.—Chimneys are built up of separate rings or courses; the length of the courses depends on the size of the plates used in their construction. Plate-iron varying from No. 6 to No. 12 W. G. is used for large chimneys, the lower courses being made of heavier iron than the upper courses. The upper end of the chimney is stiffened by making it flaring, or by riveting a heavy wrought-iron band around it on the outside. The longitudinal as well as the transverse seams of the courses are sometimes made with lap-joints; the lap of each upper course must be placed on the outside, so that the ascending currents of gas do not strike against the ends of the plates. A better and neater plan is to use butt-joints. For the longitudinal seams the butt-straps may be placed inside the pipe; the bands which connect the several courses at the transverse seams are placed on the outside.

When the chimney is bolted rigidly to the uptake the bolts pass in some cases through the flanges of angle-irons riveted around the top of the uptake and around the base of the smoke-pipe, or a stout iron band is riveted around the upper end of the uptake, and the lower end of the pipe fits into this band and is firmly bolted to it. With such a rigid attachment of the chimney to the uptake great strains are often thrown on the boiler when the ship rolls, especially when the stays are not adjusted with great exactness. On this account it is better not to attach the chimney rigidly to the boiler, but to let it simply rest on the uptake. In such a case the base of the chimney is reinforced by a stout iron ring riveted to it, which fits, with sufficient clearance to allow for expansion and irregularity of form, in an annular space formed on the top of the uptake by a ring of angle-iron riveted around the mouth of the uptake; the latter projects generally a few inches within the chimney.

The chimney is held in position by stays attached to lugs secured to the bands which connect the upper courses, and leading to eye-bolts placed on the upper deck of the vessel. When these stays are formed by chains they are attached to the eye-bolts on the deck by short lengths of rope or marline, so as to make their length adjustable and to give them some elasticity. The stays are sometimes provided with turn-buckles, in order to make them adjustable. For appearance' sake chimneys are often made to rake aft, but such an arrangement serves no practical purpose.

A cylindrical casing surrounding the lower part of the chimney, and extending from the top of the uptake to a height of several feet above the upper deck, forms an annular space, generally from three to four inches wide, around the pipe, through which the air can circulate freely, intercepting the heat radiated from the chimney. This casing is made of No. 10 or No. 12 W. G. iron, and is stiffened at the top by a heavier wrought-iron band. It is secured to the hatch-coaming of the upper deck. In some cases it

rests on the top of the boilers, openings being cut at the lower end for the circulation of the air. The top of this jacket projects within the "*apron*," which is a cover riveted to the chimney to protect the annular space between the jacket and the pipe from rain, etc., while it allows the free escape of the rising air-currents. For the further protection of the surrounding wood-work against the heat of the chimney an annular copper tank, from 2½ to 3 inches wide, filled with water, is often secured around the air-casing within the hatch.

The following directions were attached to the drawing of a chimney, 72 inches in diameter and 64 feet high, designed for the U. S. S. *Algoma* and class in 1866:

"Each pipe to be made of seven sections vertically, of the best charcoal-iron. The plates of the three lower sections to be made of No. 6 W. G. iron, and those of the four top sections to be made of No. 8 W. G. iron. The vertical seams to be butted with strips of iron on the inside; the joints to be made very close; rivets to have button-heads on the outside. The horizontal joints to be made with neat wrought-iron bands on the outside. The bands of the first and second joints from the top to have each eight lugs for stays. Sixteen stays to be provided for each pipe, of suitable length, in links of wrought-iron ½ inch in diameter, with proper attachments to the deck."

4. Hoisting-chimneys.—Hoisting or telescopic chimneys are made with one or two movable sections, which generally slide within a lower fixed section. In the 'Traité élémentaire des Appareils à Vapeur de Navigation,' by Ledieu, an illustration is given of a telescopic chimney of oval cross-section with the hoisting part larger than the standing part, so that it slides outside the latter within the air-casing. This arrangement seems to have been adopted because the standing part of the pipe is divided by a partition lengthwise into two separate passages. In another example given in the same work, where the standing part is divided in a similar manner, a separate semi-cylindrical pipe slides within each division of the fixed pipe.

The usual mode of constructing telescopic chimneys for United States naval vessels is illustrated on Plate XVII.

The chimney of the U. S. S. *Plymouth* (see Plate XVII.) is circular in cross-section and has one movable part. The fixed pipe has an inside diameter of 76½ inches and is made of No. 6 W. G. iron. The movable pipe has an inside diameter of 72 inches and is made of No. 8 W. G. iron. The plates forming each course are butt-jointed, being riveted to longitudinal wrought-iron bars, $\frac{7}{16}$ inch thick and 3½ inches wide, placed inside the fixed and outside the movable pipe; the heads of the rivets are countersunk in the bars. The several courses are connected by circumferential butt-straps placed outside the pipes. The top of the fixed pipe, as well as that of the movable pipe, is

stiffened by an iron band, 4 inches wide and about $\frac{1}{2}$ inch thick, riveted to the pipe on the outside. To each of these bands are secured six wrought-iron links for the attachment of stays. A wrought-iron ring, $1\frac{1}{4}$ inches thick and 2 inches wide, is riveted around the top of the fixed pipe on the inside. Similar rings are riveted on the outside of the movable pipe, one at the bottom and one at a distance of 34 inches from the bottom. When the movable pipe is lowered it rests with the bottom ring on the top of the uptake; when it is hoisted to its full height the second outside ring bears against the inner ring around the top of the fixed pipe, forming as close a joint as practicable. The longitudinal bars form ways for guiding the pipe when it is being raised or lowered. To prevent jamming a clearance of $\frac{3}{16}$ inch is left between the ways and the $1\frac{1}{4}$-inch rings when the movable pipe is concentric with the fixed pipe. To support the movable section when hoisted four steel bolts are tapped through composition sleeves secured at a suitable height to the fixed pipe. When the bolts are run in after the pipe is hoisted its bottom ring rests on these bolts.

The pipe is hoisted by four wire ropes, $\frac{5}{8}$ inch in diameter, leading over pulleys, 7 inches in diameter, secured to the top of the fixed pipe. One end of each wire rope is attached to a lug or eye-bolt fixed to the bottom ring of the movable pipe, suitable openings being cut in the upper part of the fixed pipe and in the lower part of the movable pipe to let the wire ropes pass through. The other end of each rope leads either directly or over guide-pulleys to a windlass carrying four drums fixed to one horizontal shaft. This windlass is mounted over the hatch of the lower deck, and is operated by a hand-crank attached to an endless screw which gears in a wheel secured to the shaft carrying the drums.

Two windlasses, placed on opposite sides of the chimney, may be used, each carrying two drums. These two windlasses are either operated independently of each other or they are connected by means of bevel-gearing on a shaft provided with hand-cranks. Steam-power may be used instead of hand-power in hoisting the pipe, without changing the arrangement of the drums materially. Sometimes each rope leads to an independent drum operated by a hand-crank and suitable gearing; but in this case it is found difficult to maintain an equal tension on all the ropes in hoisting the pipe. When several drums are fixed to a common shaft the ropes must be provided with an arrangement for adjusting them readily to the proper length and tension; for this purpose the shank of the eye-bolt to which each rope is attached passes through a lug fixed to the pipe, and is secured by means of two nuts, one placed above and the other below the lug.

The chimney of U. S. S. *Nipsic* has two movable sections. The fixed pipe has an

inside diameter of 79 inches and a length of 16 feet, and is made of No. 7 W. G. iron. The lower movable pipe has an inside diameter of 74 inches and a length of 17 feet 3 inches, and is also made of No. 7 W. G. iron. The upper movable pipe has an inside diameter of 69 inches and a length of 16 feet 10 inches, and is made of No. 8 W. G. iron. All seams of these pipes are made with butt-joints; the longitudinal butt-straps are $\frac{3}{8}$ inch thick and $3\frac{1}{2}$ inches wide, placed inside the fixed pipe and outside the two movable pipes; the heads of the rivets are countersunk in the straps. Each pipe is stiffened at the top by a wrought-iron band, 4 inches wide and 1 inch thick, placed on the outside of the pipe. The bottom end of each pipe has on the outside a wrought-iron band 2 inches wide and from $1\frac{1}{2}$ to $1\frac{3}{4}$ inches thick. A similar ring is placed around the top of the fixed pipe and of the lower movable pipe on the inside. When the pipes are hoisted to their full height the rings at the bottom of the movable sections bear against similar rings secured inside the fixed and the lower movable pipes, 26 inches from the top of the pipes.

The upper section is hoisted simultaneously with the lower movable section by means of four wire ropes. One end of each rope is secured to the top of the fixed pipe. Passing over a pulley attached near the top of the lower movable section, the rope leads down between the upper and lower movable pipes, and has its other end attached to the band at the bottom of the upper movable pipe.

The hoisting-gear of the lower movable pipe is of a novel design. A chain, made of $\frac{3}{4}$-inch iron, has both ends attached to a wrought-iron beam fixed across the lower end of the movable pipe, and passes then over two stationary pulleys secured to the upper end of a pipe 18 inches in diameter, which is fixed centrally within the standing part of the chimney and leads down through the uptake into the fire-room. The bight of the chain passes around a movable pulley within this central pipe. This pulley carries a swivel, to which the end of a chain, made of one-inch iron, is attached, that leads down through the central pipe to a drum in the fire-room. The drum is revolved by hand-power and suitable gearing.

When the chimney is hoisted it has a height of 44 feet and 1 inch, measured from the bottom of the standing pipe. When the chimney is lowered the lower movable section rests on the top of the fixed pipe, and the upper movable section rests on the top of the lower movable section; and the total height of the pipe, measured from the bottom of the fixed pipe, is 18 feet $\frac{5}{8}$ inch.

Double-hoist chimneys have less height when lowered than single-hoist chimneys; this is, in fact, the only advantage possessed by the former over the latter. On the other hand, all the disadvantages connected with the use of all hoisting-pipes are greatly in-

creased in the case of the former. Compared with fixed pipes the disadvantages of hoisting-pipes are as follows: they occupy more room in the hatch and are heavier; their first cost is far greater; they are more liable to accidents, and much labor is required to keep their gear in working order; they are less efficient on account of the sudden changes in their cross-sections and because air-leaks are unavoidable with them.

In the U. S. S. *Quinnebaug* and class the chimney is made with one movable section, and the height of the pipe above deck, when lowered, is reduced by letting the movable section pass through an opening in the bottom of the uptake and rest on the floor of the fire-room. When the pipe is hoisted the opening in the uptake is closed by a door secured by clamps. The lower part of the movable pipe has two large openings opposite to each other, provided with doors, in order to form a passage between the forward and after parts of the fire-room when the pipe is lowered.

5. Artificial Draught: Blast-pipe, Steam-jets, Fan-blowers.—To attain the best possible natural draught with a given height of chimney the temperature of the column of hot gas within the chimney has to be so great that from 25 to 33 per cent. of the total heat generated by the combustion of the fuel is expended in producing the draught. (*See section* 11, *chapter* ii., *and section* 7, *chapter* iii.) When the height of the chimney and the bulk and weight of the boiler are limited, artificial draught has to be used for increasing the evaporative power of the boiler beyond a certain limit. Artificial draught has the great advantages that, all things considered, it is cheaper than natural draught for high rates of combustion, and that it can be readily adjusted for the combustion of different kinds of fuel and for widely different rates of combustion, so that a given boiler may be worked under greatly varying conditions.

The general measure of the efficiency of the mechanism for producing artificial draught is the ratio of the power expended in operating the mechanism to the increase of draught produced; the increase of draught may be measured by the increase in the rate of combustion. With a given boiler the value of a mechanism for producing artificial draught depends not only on its efficiency as measured by the foregoing rule, but on the economic evaporative efficiency of the boiler with different rates of combustion; on the weight and bulk of the mechanism; on its first cost; and on the labor and expense of operating it and keeping it in working order.

Artificial draught is produced either by diminishing the resistance of the column of gas within the chimney or by increasing the pressure of the atmospheric air under the grate.

To produce the first of these conditions a fan-blower has been used for exhausting the gases escaping up the chimney; but this method has not come into general use on account of practical difficulties. The ordinary method is to use a jet of steam in the

chimney, which balances by its impact the weight of the column of gas within the chimney. The action of the class of "*fluid-on-fluid impulse machines*," to which the jet belongs, is described by Rankine in the following words: "A stream of fluid, moving at first with a certain velocity, drives and carries along with it an additional stream, the two streams finally mingling and moving together with a velocity less than that of the driving stream."

In locomotives the blast is produced by discharging the exhaust steam from the cylinders into the chimney. This plan can, of course, be used only with high-pressure, non-condensing engines, and is applied to many river-boats and to tug-boats and similar small craft. The efficiency of such a blast is to be measured by the increase of the evaporative power of the boiler relatively to the increase of back-pressure produced in the steam-cylinders.

"The effect of the blast-pipe in producing a draught depends upon its own diameter and position, on the diameter of the chimney, and on the dimensions of the fire-box, tubes, and smoke-box. Mr. D. K. Clark has investigated the influence of these circumstances from his own experiments and from those of Messrs. Ramsbottom, Polonceau, and others, and has shown that the vacuum in the smoke-box is about 0.7 of the blast-pressure; that the vacuum in the fire-box is from $\frac{1}{3}$ to $\frac{1}{2}$ of that in the smoke-box; that the rate of evaporation varies nearly as the square root of the vacuum in the smoke-box; that the best proportions of the chimney and other parts are those which enable a given draught to be produced with the greatest diameter of the blast-pipe, because the greater that diameter the less is the back-pressure produced by the resistance of the orifice; that the same proportions are best at all rates of expansion and at all speeds; and that the following proportions are about the best known:

Sectional area of tubes within ferrules	$= \frac{1}{5}$ area of grate.
Sectional area of chimney	$= \frac{1}{15}$ area of grate.
Area of blast-orifice (which should be somewhat below the throat of the chimney)	$= \frac{1}{65}$ area of grate.
Capacity of smoke-box	$= 3$ feet $\times$ area of grate.
Length of chimney	= four times its diameter.

"If the tubes are smaller the blast-orifice must be made smaller also—for example, if

Sectional area of tubes within ferrules	$= \frac{1}{10}$ area of grate,
Then area of blast-orifice	$= \frac{1}{90}$ area of grate."

(*Rankine, 'Manual of the Steam-engine.'*)

When condensing-engines are used the steam-jet is supplied directly from the boiler. Its efficiency is to be measured by the increase of evaporative power of the boiler relatively to the weight of steam expended in the jet. The increase of draught produced by the jet depends on the velocity with which a given weight of steam strikes against the column of gas within the chimney, and on the area of that column immediately acted upon by the jet. C. Wye Williams found by experiment that thirty jets of one-tenth inch sectional area, placed three inches apart, were more effective than sixty jets of one-quarter inch sectional area placed one inch apart, and, moreover, saved an enormous amount of steam.

Isherwood says ('Experimental Researches,' vol. ii.): "It is found experimentally that with a properly-constructed steam-jet, composed of small brass nipples or hollow truncated cones inserted in concentric rings of steam-pipe, placed in the smoke-pipe about two feet above its bottom, the rings being so spaced as to equally distribute the area of the smoke-pipe over them, and the nipples being three inches between centres on the rings, the expenditure of steam of 40 lbs. per square inch above the atmosphere by the jet to raise the rate of combustion in the water-tube boiler from $15\frac{5}{8}$ lbs. per square foot of grate per hour to 24 lbs., the air-supply to the ashpit being copious and not brought at the expense of the draught, is 7.22 per centum of the total evaporation."

The jet arrangement designed for the chimney of the U. S. S. *Algoma* and class (described in section 3 of the present chapter) consisted of three rings of gas-pipe arranged in a pyramidal form above one another, with a vertical distance of 16 inches between them, and connected with one another by four branch-pipes screwed into couplings. These rings were made of 3-inch, $2\frac{1}{2}$-inch, and 2-inch pipe, and had an outside diameter of 65 inches, $48\frac{1}{2}$ inches, and 32 inches respectively, the larger pipe and ring being at the bottom and the smaller pipe and ring at the top of the system. The steam-jets issued through brass nipples screwed into the rings and placed $3\frac{1}{2}$ inches apart. These nipples were $\frac{11}{16}$ inch long; the opening through them was conical, decreasing from $\frac{1}{4}$ inch near the bottom to $\frac{1}{16}$ inch near the top, and flared at the bottom and at the top to $\frac{1}{2}$ inch and $\frac{1}{4}$ inch respectively.

When a fan-blower is used to force a supply of air directly under the grates the ashpit-doors and furnace-doors are closed tight, and the mouths of the ducts which convey the air from the blower enter the ashpit either through openings at the back of the boiler or in front through openings in the ashpit-doors. Each branch-duct is provided with a valve to shut off the air-supply from any furnace when it is necessary to open the ashpit or furnace doors.

The net power required to work a blower may be calculated by means of the formula given in section 12, chapter ii.

"The quantity of steam required to work the fan-blower rapidly enough to produce a combustion of even 35 lbs. of anthracite per square foot of grate-surface per hour is quite an insignificant per centum of the total evaporation. Such an apparatus is by far the most economical method of producing the draught; but as the blast must be delivered beneath the grate-bars, with air-tight ashpit-doors, the ventilation of the fire-room is almost wholly destroyed by it, and the firemen, with boilers in the hold of vessels, find the heat and dust insupportable. The fan-blower is generally worked by a small independent steam-cylinder, and in a vessel the space occupied by the apparatus and its weight are considerable; also, the trouble of looking after the numerous cocks, valves, etc., connected with it, and the unavoidable complexity attending additional machinery, have operated to its exclusion on board of marine steamers." (*Isherwood*, '*Experimental Researches*,' vol. ii.)

Sometimes, instead of forcing the air directly into the ashpits, it is delivered into the fire-room, which is enclosed by air-tight bulkheads and decks, and has no outlet for the air except through the grates. In this manner an increased barometric pressure is produced within the fire-room. The boilers are worked with open ashpits, and the ventilation of the fire-room is as perfect as with natural draught. When, however, the space is not quite air-tight a waste of power ensues; and this can scarcely be avoided. This plan has been adopted to advantage in iron-clad batteries, torpedo-boats, and similar vessels, which have to be constructed with tight decks, and are, consequently, dependent upon artificial means for ventilation and a supply of air to the furnaces.

In some instances air has been forced through nozzles into the closed ashpits by means of steam-jets; and in the place of steam-jets a blast of air supplied by a fan-blower has been tried in the chimney.

Koerting's jet apparatus consists of a series of short nozzles gradually increasing in size (see figure 1, Plate XXXV.) According to the inventor the number and dimensions of these nozzles are determined by the following considerations: 1st, to make the velocity of the motive fluid a maximum as it escapes under a varying back-pressure; 2d, to produce an intimate mixture of the propelling fluid with the fluid to be set in motion.

The tube admitting the propelling fluid is fixed obliquely at the side of the smallest nozzle, the opening of which can be varied by a screw in order to regulate the admission of steam or compressed air. The annular openings between the nozzles, admitting the air to the propelling jet, gradually increase in width as the distance from the open-

ing admitting the steam increases and the velocity of the jet decreases. Provision is made sometimes to vary the relative position of the conical nozzles by means of a screw, in order to regulate the width of the annular spaces.

In the first nozzle the steam-jet is mixed with a certain quantity of air and forms with it a new jet, which becomes mixed in the successive nozzles with additional quantities of air entering through the annular spaces. The jet gradually decreases in velocity, while the volume of air set in motion increases proportionately. The velocity attained in the last nozzle corresponds to the required pressure.

The apparatus represented in figure 1, Plate XXXV., is designed to force air under the grate of a boiler or other furnace. With an initial steam-pressure of 40 lbs. per square inch the pressure of air produced by this apparatus is equal to a head of 2 inches of water.

Apparatus of similar construction are used for steam-jets in chimneys.

6. Experiments with Artificial Draught in Marine Boilers.—In the years 1865–66 experiments were made at the United States Navy-Yard, New York, with various devices for increasing by artificial means the rate of combustion in marine boilers. Steam and air jets of various forms and dimensions, and located at different heights within the chimney, were tried, and air was forced into closed ashpits by means of fan-blowers and steam-jets of various dimensions. These experiments were further varied by altering the dimensions of the grates and the ratios of calorimeter and heating-surface to grate-surface. The results of these experiments are tabulated in the Report of the Board of Engineers convened by the United States Navy Department to make experiments with the horizontal fire-tube boiler and the vertical water-tube boiler of the Martin type, for the purpose of determining the relative merits of these two types of marine boilers. Since the primary object of these experiments was not to determine the relative efficiency of the various devices used for producing artificial draught, the results of all the experiments are not comparable. The experiments with the vertical water-tube boiler were much more numerous and varied than those with the horizontal fire-tube boiler, therefore only the former will be considered; and, in order to eliminate as much as possible all uncertain elements, only those will be selected for comparison which were made without altering the heating-surface and calorimeter of the boiler, and in which the grate either had its original length of 6 feet 6 inches or was shortened to 6 feet so as to reduce the grate-surface to 36 square feet.

The vertical water-tube boiler, which was built expressly for the purpose of these experiments, had two furnaces, each 36 inches wide and containing a grate 6 feet 6

inches long. It had a separate chimney 35 inches in diameter and 60 feet high above the grate, and it contained 748 brass tubes of 2 inches external diameter and $28\frac{1}{2}$ inches long.

Total grate-surface	39 sq. ft.
Total heating-surface	1264.81 sq. ft.
Ratio of grate to heating-surface	1 to 32.43
Ratio of grate to calorimeter of tubes	7.04 to 1
Ratio of grate to calorimeter of chimney	5.79 to 1

Each experiment lasted from 48 to 80 hours continuously. In the experimental boiler the evaporation took place under atmospheric pressure. The steam for operating the jet or fan was supplied by an independent boiler, in which the pressure ranged from 25 to 40 lbs. per square inch above the atmosphere. The water supplied to both these boilers was measured in separate tanks. The coal was Pennsylvania anthracite of "egg-size," free from dust, and the amount used was accurately weighed.

The quantities given in columns b, c, d, e of the following table are taken directly from the tables accompanying the above-mentioned report, except when they represent the mean results of several experiments, which are calculated from the quantities given in the original tables. The quantities contained in columns f, f_1, g, g_0, h, h_0, j, j_0 are calculated from the results recorded in the original tables.

Column f shows the quantity of steam expended for blast in per centum of the total weight of water evaporated, and column f_1 the weight of water of 212° Fahr. evaporated under atmospheric pressure equivalent to the actual weight of steam expended for blast per hour.

Columns g, g_0 show the quantity of steam, in pounds, available for useful work, or the difference of the weight of steam expended for blast and of the total weight of water evaporated.

Columns h, h_0 and j, j_0 show the cost of producing the increase in the rate of combustion and in the evaporative power of the boiler in each experiment, expressed in pounds of steam expended in blast for each additional pound of coal burned and of water evaporated respectively.

On account of the unavoidable differences in the quality of the coal, and on account of the influence of the variations in the rates of combustion on the economic evaporative efficiency of the boiler, the tabulated results indicate only approximately the relative value of the various methods tried.

Comparing the results of experiments Nos. 3, 4, 5, 6, and 7, it will be seen from

columns h, h_0 that when the jet-coil is supplied with nozzles of proper form and dimensions the efficiency of the steam-jet is nearly twice as great as when the steam issues through plain holes drilled in the coil. Columns h, h_0 indicate likewise that in experiments Nos. 4, 5, 6, and 7 the weight of steam expended for each additional pound of coal consumed did not vary greatly.

Comparing experiments Nos. 8, 9, 10, 11, 12, and 13 with the preceding ones, it appears that the large single nozzle produced on the whole a better useful effect than the steam-jet consisting of numerous small nozzles. This result, which apparently contradicts other experiments, may be explained by the fact that the chimney was not of large diameter, and that the coils of the jet-pipe formed a serious obstruction to the passage of the gases in the smoke-pipe. To preserve the proper calorimeter the smoke-pipe was enlarged to a diameter of 38 inches at the place where the jet-coil was situated; a better result would probably have been obtained by giving to the coil the pyramidal form described in section 5 of this chapter, since it obstructs less the cross-section of the pipe.

The height of the single jets above the grate was varied in several experiments without producing any marked difference in the results. When, however, the jet was placed only 6 feet below the top of the chimney it became ineffective. A single steam-jet placed in each back-connection showed likewise no useful results.

The great efficiency of the fan-blower in increasing the rate of combustion by forcing air into closed ashpits is illustrated in columns h, h_0, experiments Nos. 16, 17, and 18; and columns j, j_0 show how far the relative economy of this system of forcing the draught is maintained for high rates of combustion with decreased economic evaporative efficiency of the boiler. In experiment No. 18 the economic evaporation falls so low that the boiler actually furnishes less *available* steam than in experiment No. 17, although the rate of combustion is nearly 33 per cent. greater in the former case than in the latter. This great falling-off in economic evaporation is probably to some extent owing to the fact that too large an amount of air entered the furnaces relatively to the weight of fuel consumed, and a better result might have been obtained if a thicker bed of fuel could have been maintained or if coal of smaller size had been used. With smaller coal the interstices affording passage to the entering air are more numerous, narrower, and more tortuous, and a larger amount of surface of the incandescent fuel is presented to the air. A great increase in efficiency has resulted in some cases from the use of smaller coal with forced draught.

TABLE XXXVII.

SHOWING RESULTS OF EXPERIMENTS MADE AT THE NAVY-YARD, NEW YORK, IN THE YEARS 1865–66, WITH VARIOUS DEVICES FOR PRODUCING ARTIFICIAL DRAUGHT IN MARINE BOILERS.

No.	Conditions of experiments.	Grate-surface, sq. ft.	Pounds of coal consumed per sq. ft. of grate-surface per hour.	Percentage of refuse in coal.	Pounds of combustible consumed per sq. ft. of grate-surf. per hr.	Pounds of water evap. from 212° F. under atmospheric pressure (29.922 ins. Bar.) per lb. of combus.	Steam expended for blast in p. c. of total am't of wat. evaporated.	Pounds of steam expended for blast per hour.	Pounds of steam generated per hour, less quantity expended for blast.		Steam expended for blast, in lbs. of water evap'd from 212° F. under atmos. pres. per lb. of coal consumed per sq. ft. of grate above the highest rate of combust. with natural draught.		Pounds of steam expended for blast per lb. of steam available for useful work above the largest amount evaporated with natural draught.		No.
									Area of grate, 39 sq. ft.	Area of grate, 36 sq. ft.	Area of grate, 39 sq. ft.	Area of grate, 36 sq. ft.	Area of grate, 39 sq. ft.	Area of grate, 36 sq. ft.	
		a	*b*	*c*	*d*	*e*	*f*	f_1	*g*	g_0	*h*	h_0	*j*	j_0	
1	Highest rate of combustion with natural draught. Mean results of five experiments	39	16.04	22.94	12.36	11.752	....	....	5,665	....	....	....	....	....	1
2	Highest rate of combustion with natural draught. Mean results of three experiments	36	14.08	20.67	11.17	12.387	....	....	....	4,981	....	....	....	....	2
3	Steam-jet of 37 holes in plane coil of two convolutions, placed in chimney 13.33 feet above grate. Holes 1-10 inch diameter, spaced 3 inches apart	39	19.66	17.44	16.23	10.543	10.20	680	5,992	....	4.82	....	2.081	....	3
4	Steam-jet of 36 nozzles, in same coil as in previous experiment. Nozzles ½ inch long, .064 inch least internal diameter, and spaced 3 inches apart	39	19.77	18.78	16.05	11.020	5.55	383	6,516	....	2.63	....	.449	....	4
5	Steam-jet of 36 nozzles, in same coil as in previous experiment. Nozzles spaced 3 inches apart, least internal diameter .07 inch	36	19.42	21.99	15.15	11.000	7.17	430	....	5,569	....	2.24	....	.732	5
6	Steam-jet of 69 nozzles, in a horizontal system of 1-inch pipes connected by a central pipe (gridiron shape). Nozzles ½ inch long; least internal diameter = 1-16 inch; distributed so as to act on equal areas of the smoke-pipe	36	22.03	16.66	18.36	10.640	8.68	611	....	6,420	....	2.13	....	.424	6
7	Highest rate of combustion produced by a steam-jet of 40 nozzles, of .058 inch least internal diameter and .821 inch long, in two concentric rings placed 13.25 feet above grates; using 40 pounds of steam for jet. Rings 29¼ and 15⅝ inches diameter	36	17.15	19.47	13.81	12.879	4.29	275	....	6,128	....	2.49	....	.240	7
8	Highest rate of combustion produced by steam-jet of a single nozzle, 3.259 inches long and .284 inch least internal diameter, placed in centre of chimney, 13.25 feet above grates. Steam for jet, 40 pounds	39	18.08	18.27	14.78	11.819	3.54	241	6,574	....	3.03	....	.266	....	8
9	Conditions same as in preceding experiment	36	18.33	19.50	14.75	12.944	3.48	239	...	6,634	....	1.56	....	.145	9
10	Single jet; nozzle 3.924 inches long and .368 inch least internal diameter, placed 13.25 feet and 18 feet above grates. Mean results of four experiments	39	20.17	18.59	16.42	11.654	4.45	332	7,132	....	2.06	....	.226	....	10
11	Single jet; nozzle same as in last experiments; placed 13.25 feet, 25 feet, and 35 feet above the grates. Highest rates of combustion. Mean results of three experiments	36	19.23	17.78	15.81	12.616	4.67	336	....	6,846	....	1.81	....	.180	11
12	Single jet; nozzle 4.5 inches long and .425 inch least internal diameter, placed 13.25 feet above grates. Steam for jet, 40 pounds. Highest rate of combustion	39	19.10	16.80	15.89	12.100	5.85	439	7,061	....	3.68	....	.314	....	12
13	Same conditions as in preceding experiment. Mean results of two experiments	36	21.66	18.84	17.58	11.375	6.01	433	.. .	6,765	....	1.59	....	.243	13
14	Highest rate of combustion with jet of 3 nozzles, 3-16 inch least internal diameter, placed horizontally in mouth of each ashpit in conical air-pipes of 2½ inches least diameter; ashpit-doors closed	36	18.03	19.73	14.47	12.002	7.93	496	....	5,756	....	3.49	....	.640	14
15	Jet same as in preceding experiment, but nozzles ¼ inch least diameter, with a solid centre 3-16 inch diameter, leaving annular space 1-32 inch wide. Air-tubes 3½ inches diameter	36	19.12	20.81	15.14	12.810	5.95	415	...	6,566	....	2.29	....	.262	15
16	Forced combustion by a Dimpfel blower, 3 feet diameter, with tuyere 8 inches square, admitting air through front of ashpit	36	26.30	17.66	21.65	9.234	4.56	328	....	6,870	.. .	.75	....	.174	16
17	Conditions same as in preceding experiment	39	24.52	18.19	20.06	9.801	3.98	305	7,362	....	.92	....	.180	....	17
18	Burning the greatest amount of coal possible when forcing all the blast possible under the grates with a Dimpfel blower of 3 feet diameter	39	32.38	16.83	26.93	7.174	6.37	480	7,055	....	.75	....	.345	....	18

CHAPTER XIII.

STEAM-ROOM AND SUPERHEATERS.

1. Capacity of Steam-room.—Too large a steam-room not only increases the bulk and weight of the boiler unnecessarily, but increases its heat-radiating surface. It is useless to increase the steam-space beyond a certain limit for the purpose of storing up steam to meet any sudden demand arising from irregular loads on the engines; for a simple calculation will show that the heated water contained in the boiler can be relied upon for a far greater supply of steam in case of a sudden emergency than could be obtained by any admissible increase in the capacity of the steam-room.

When the capacity of the steam-room is small relatively to the quantity of steam drawn from the boiler per stroke of engine, the pressure in the boiler fluctuates greatly. Any sudden fall of pressure causes a violent ebullition of the water heated to the boiling-point, producing injurious pulsations and priming. To diminish the fluctuations of pressure in the boiler the latter must carry a large amount of water relatively to the amount evaporated in a unit of time, and the capacity of the steam-room must be proportioned to the capacity of the cylinders. With engines working with a high rate of expansion, and making relatively few revolutions per minute, the capacity of the steam-room has to be relatively greater.

Authorities differ as to the best proportions of steam-room and water-room in boilers. According to Bourne ('Handbook of the Steam-engine'), the total capacity or bulk of a marine boiler, exclusive of chimney, is usually about 8 cubic feet for each cubic foot of water evaporated per hour, divided in the proportion of 6.5 cubic feet devoted to the water, furnaces, and tubes, and 1.5 cubic feet occupied as steam-room. The capacity of the steam-room of several boilers illustrated in this book will be found in Table XXII., chapter vii.

In the French navy experience has developed the fact that, with rectangular boilers of ordinary dimensions of the type illustrated in figure 106 and on Plate XVII., and burning about 20 lbs. of coal per square foot of grate as a maximum, when the capacity of the steam-room is equal to the volume of steam consumed by the engines during 14

seconds, no water is carried over into the cylinders; but when it contains steam for only 12 seconds the steam is generally very wet. With cylindrical boilers working with high pressures, and having a capacity of steam-room equal to the volume of steam consumed by the engines during 16 seconds, water is carried over at times; while similar boilers containing steam for 20 seconds give no such trouble.

When the steam-room is contained partly in a steam-drum to which the steam-pipe leading to the engines is connected, the opening by which the drum communicates with the steam-space within the shell of the boiler must be arranged in such a manner that the steam has no tendency to enter with a violent rush, lifting the water or carrying it along in the form of spray. Height of steam-space is important especially in marine boilers, in which the water is frequently greatly agitated in consequence of the motion of the vessel.

Height of steam-room is also necessary in order to afford vertical space for the separation from the steam of the water carried up with it mechanically. This separation is effected by the greater gravity of the water enabling it to fall back after being carried to a certain height, so that a definite height is absolutely necessary for the operation. No amount of steam-room a few inches high will enable a boiler to furnish dry steam, while with a considerable height a comparatively small volume of steam-room will be efficient.

The greater value of steam-drums upon a boiler than their volume of steam-room within the shell is due to the simple fact of their greater height. The real purpose of the drum is not so much to gain increased steam-room as increased height of steam-room. And the wonderful efficiency of steam-chimneys, as they are called—that is, annular steam-drums enveloping concentrically the base of the chimney—arises not only from the superheating which the steam obtains in them, but from the very considerable height given to them, whereby the water entrained by the steam has time and space to become separated very thoroughly by its greater gravity.

2. Steam-drums.—In rectangular boilers of naval vessels the steam-space is generally contained entirely within the shell, although sometimes a low steam-drum, surrounding the uptake, is added. Cylindrical and semi-cylindrical boilers are nearly always provided with steam-drums, which generally form an annular space around the base of the chimney; with this arrangement the steam-drums occupy the most convenient place in the boiler-hatch, and a considerable amount of superheating-surface is gained. These drums are either built directly on the top of the boiler, their bottom being open to the steam-space, or they are separate structures which are connected by pipes, provided with stop-valves, with the steam-space within the shell of the

boiler. In merchant-vessels the steam-drums are generally placed vertically on the top of the boilers, in order to gain additional height of steam-space. In war-vessels they lie horizontally in the upper spandrels formed by the cylindrical shells of each pair of adjacent boilers, and are greatly less efficient. All steam-drums should be provided with manholes, and should be made roomy enough to be accessible for examination and cleaning. They should be provided with drain-pipes for drawing off any water which may have been carried into them by priming or formed within them by the condensation of the steam.

When a steam-drum or dome is built vertically on the cylindrical shell of a boiler it is the usual practice to cut a hole, corresponding in diameter to the drum, in the shell of the boiler, and secure the cylindrical drum to the shell by means of an angle-iron ring. When the drum is not of large diameter, as in locomotive boilers, the top is often made hemispherical to avoid the use of stays. It is evident that the cylindrical shell is very much weakened by the large hole, unless a heavy wrought-iron strengthening-ring is riveted around the opening. Sometimes, instead of cutting a large opening in the shell, a great number of small holes are drilled in the shell to establish communication between the steam-space within the boiler and the interior of the drum. The perforated plate is intended to check a rush of water into the drum and to cause less reduction of strength of the boiler-shell. The only addition given by it to the strength of the shell is what is due to the *stiffness* of the curved plate. In other cases the shell is cut away only sufficiently to allow a man to pass from the boiler into the dome, the opening being made, however, so large that the rush of steam through it does not induce priming.

In these cases the portion of the shell which forms the bottom of the drum is not subjected to direct tension, like the rest of the shell, by the pressure of steam. Consequently the tangential forces due to the tension on the shell tend to straighten this portion of the shell, and to open out the lower part of the cylindrical shell of the drum, and thus throw a strain on the flange of the drum at the opposite sides. To prevent this strain the bottom of the drum must be subjected to a tension equal to that on the rest of the shell, which may be effected to a certain extent by making the top of the drum flat and tying it by vertical rods to the cylindrical boiler-shell forming the bottom of the drum.

Straight braces may also be placed across the opening of the drum transversely to the shell, thus restoring, in a measure, the strength due to the portion of the shell cut out for the drum.

In small cylindrical boilers the vertical steam-domes are sometimes made with a

spherical top and with a contracted neck at the bottom. This neck is made of stout material and with a broad flange, which serves to compensate in a great measure for the loss of strength due to cutting a hole in the shell of the boiler.

3. Superheaters.—The general principles according to which the theoretical and the practical efficiency of superheaters are to be determined have been stated in sections 9 and 10, chapter iii.

In nearly all marine boilers a portion of the uptake passes through the steam-space, and, in a measure, dries or superheats the steam. In all sectional water-tube boilers the tubes forming the steam-space act as efficient superheaters, and in launch boilers the steam passes frequently through a coiled pipe in the uptake before it is led off to the engine. In the vertical fire-tube boiler the water-level is carried some distance below the upper tube-sheet, and the upper ends of the tubes and the uptake form superheating-surfaces. In the vertical water-tube boiler of the Martin type, likewise, the water may be carried with safety several inches below the upper tube-sheet, and efficient superheating-surface will thus be gained. The vertical steam-drums of marine boilers are commonly traversed by one or several large flues for the purpose of drying or superheating the steam. In some cases the steam-drum surrounding the base of the chimney is divided by partitions into several compartments, which communicate with one another by openings at opposite ends in such a manner that the steam has to pass in succession through all the different compartments before it enters the steam-pipe, and thus is forced to remain a longer time in contact with the superheating-surface.

In the high-pressure cylindrical boilers of United States naval vessels superheating-surface is provided by letting the steam-pipe pass several times through the whole length of the uptakes along the fronts of the boilers.

By means of flues traversing or surrounding the steam-drum or the upper part of the boiler the steam may be effectually dried and its temperature may be raised to a point exceeding somewhat, but not very much, the boiling-point corresponding to the pressure in the boiler. When a much higher temperature is to be given to the steam the superheating has to be effected in a separate chamber containing a larger amount of heating-surface than can be obtained conveniently by the above-mentioned arrangements.

The superheater of U. S. S. *Plymouth* (see Plate XVII.) consists of a box extending along the front of the boiler and traversed by numerous vertical brass tubes, through which the products of combustion pass from the front-connections to the uptake. At one end of the box the saturated steam is admitted from the boiler through suitable

pipes and stop-valves, and at the other end the superheated steam is carried off to the main steam-pipe.

In other superheaters horizontal pipes are used, and these are often arranged in two groups connected at the ends by chambers in such a manner that the steam passes twice through the whole length of the superheater, entering through one group and returning through the other, before it is discharged into the steam-pipe.

Superheaters constructed of flat plates, after the plan of Lamb and Sumner's boiler (see section 1, chapter xi.), have been much used in England. Many other devices have been tried with the view of gaining a large amount of efficient heating-surface in a cheaply-constructed apparatus.

The superheaters are generally arranged in the uptake of the boiler, so as to utilize some of the heat of the escaping gases. It is evident that when a high degree of superheating is desired considerable difference must exist between the temperatures of the gases in the uptake and of the saturated steam in the boiler; and to obtain this difference the water-heating surface of the boiler must be made small relatively to the amount of coal burnt in a unit of time. Besides, the additional resistance offered by the superheating apparatus to the escaping gases makes it necessary that the chimney temperature should be correspondingly increased, in order to maintain the same rate of combustion as without the superheating apparatus.

A great increase of efficiency has been obtained in cases where such superheaters have been added to boilers already built which were subject to priming or, being deficient in heating-surface, discharged the gases at a higher temperature than was required for the desired rate of combustion. The saving in fuel expended for a given amount of work, effected by the introduction of superheating apparatus, has amounted, in a number of cases cited by Bourne ('A Treatise on the Steam-engine'), to from 18 to 34 per centum.

Superheaters of the foregoing description, with their steam-pipe connections and stop-valves, add largely to the weight and cost of boilers; and unless they are easily accessible for sweeping (which is frequently not the case), the efficiency of their heating-surface is soon impaired and the draught of the boiler is often seriously affected by the accumulation of soot. The most serious troubles, however (which have brought superheaters somewhat into disrepute), are due to the rapid corrosion of the iron of which superheaters are constructed, and to the leakage of their tubes. The rapid corrosion of superheating-surfaces has been observed for a long time, even in the case where the degree of superheating was relatively small, as in steam-drums traversed by flues, but its causes have not been definitely determined. The leakage of the tubes after short use is

probably mainly owing to the fact that, after the fires are lighted, some time elapses before steam is formed in the boiler, and the hot gases passing through the empty superheater raise the metal to an unduly high temperature. To remedy this defect it is proposed to keep the superheater filled with water until steam is formed in the boiler.

Some years ago many United States naval vessels were furnished with special superheating-boilers, one being provided for each pair of main boilers containing in all fourteen furnaces. Each superheating-boiler contained one furnace of the usual dimensions. The products of combustion, after passing through return-flues, situated over the furnace, to a front-connection, passed through a set of horizontal iron tubes to an upper back-connection, and returned thence through another set of like tubes to an upper front-connection, which communicated with the uptake of the main boilers. The lower flues of the boiler were kept covered with water, and the double-return tubes furnished the superheating-surface. The superheating-boiler communicated with the main steam-pipes through stop-valves, arranged in such a manner that the steam from the main boilers would either pass wholly or in part through the superheaters, or go directly to the engines. These boilers were efficient superheaters; but they were rapidly destroyed by corrosion, because their interior was inaccessible and the iron superheating-tubes were left without the coating of scale which protects the iron water-heating tubes of marine boilers effectually. In the U. S. S. *Congress* each of these superheating-boilers was 3 feet 10 inches wide, 10 feet 3 inches long, and 9 feet 9 inches high, and its weight complete was 19,000 lbs. The superheating effected was about 30° Fahr. above the saturation temperature.

Independent superheating-boilers possess the advantage that any degree of superheating may be obtained in them with great exactness by regulating the rate of combustion in the furnace; furthermore, the efficiency of the main boilers is entirely independent of the efficiency of the superheaters; any derangement of the latter does not affect the former. The additional space occupied by them is an important element in determining their relative usefulness; but in naval vessels it may often be advisable to sacrifice room on the floor of the vessel in order to get a lower and a more reliable boiler.

The superheating arrangement of the U. S. S. *Eutaw* (built in 1863) consisted of two groups of horizontal tubes, with the ends secured in tube-plates. Each group contained 176 iron tubes $1\frac{1}{4}$ inches in diameter and 21 inches long between the tube-plates. At one end the two groups communicated by means of a common chamber formed by an iron casting bolted to the tube-plate, and at the other end each group had a separate connection formed by an iron casting provided with a nozzle and likewise bolted to the

tube-plate. This superheater was placed in the tube-box of one of the wing furnaces of each boiler, from which the vertical water-tubes had been removed with the exception of six rows at the back of the box, left for the purpose of reducing somewhat the temperature of the gases before they impinged on the superheating-tubes. The tubes of the superheater were placed across the tube-box, and the nozzles of the connections projected through openings in the side of the boiler. To the nozzle nearest the front of the boiler a pipe bringing the saturated steam to the superheater was bolted, and to the other nozzle another pipe was bolted carrying the superheated steam to the main steam-pipe. These pipes were all controlled by stop-valves, so that the superheater could be shut off when the fire was hauled from the furnace, and the engine could be supplied with saturated steam, or superheated steam, or a mixture of saturated and superheated steam.

Each of the two boilers contained five furnaces, and the two boilers contained in the aggregate 200 square feet of grate-surface, 4,536 square feet of water-heating surface, and 1,058 square feet of superheating-surface.

Using natural draught and burning 11.67 lbs. of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 270.2° Fahr. when saturated to 365.0° Fahr. when superheated.

Using a fan-blower and burning 27 lbs. of anthracite coal per square foot of grate per hour, the temperature of the steam was raised from 295.0° Fahr. when saturated to 380.0° Fahr. when superheated.

One of the greatest practical objections to the use of separate tubular superheaters as described is the impossibility of cleaning the steam side of the surfaces. The interior of the tubes or the spaces between the tubes, as the construction may be, become filled with the mud and grease carried over from the boiler by priming or foaming, and there is no means of removing these substances without destroying the superheater.

CHAPTER XIV.

SETTING AND ERECTION OF BOILERS.

1. Setting of Boilers.—The weight of large boilers must be well distributed over the floor of the vessel. When the boilers are placed so that the fire-room runs in the fore-and-aft direction of the vessel they rest generally on two keelsons. To protect the bottom of the boilers from the bilge-water a tight platform is often built on the keelsons for the boilers to rest on.

The following directions are given by Bourne for setting flat-bottomed boilers in wooden vessels: "In the setting of marine boilers care must be taken that no copper bolts or nails project above the wooden platform upon which they rest, and also that no projecting copper bolts in the sides of the ship touch the boiler, as the galvanic action in such a case would probably soon wear the points of contact into holes. The platform may consist of three-inch planking laid across the keelsons, nailed with iron nails the heads of which are well punched down, and calked and puttied like a deck. The surface may then be painted over with thin putty, and fore-and-aft boards of half the thickness may then be laid down and nailed securely with iron nails having the heads well punched down. This platform must then be covered thinly and evenly with mastic cement and the boiler be set down upon it, and the cement must be calked beneath the boiler by means of wooden calking-tools so as completely to fill every vacuity. Coamings of wood sloped on the top must next be set round the boiler, and the space between the coamings and the boiler must be calked full of cement, and be smoothed off on the top to the slope of the coamings, so as to throw off any water that might be disposed to enter between the coamings and the boiler."

Ledieu gives the following compositions for the cement used in setting boilers—viz., equal quantities of whale-oil, ox-blood, and powdered unslaked lime; or, Spanish white, oil, and a small quantity of cow-hair.

Hamelin's mastic cement for the setting of boilers is compounded as follows: "To any given weight of sand or pulverized earthenware add two-thirds such given weight of powdered Bath, Portland, or similar stone, and to every 560 lbs. weight of the mixture add 40 lbs. weight of litharge, 2 lbs. of powdered glass or flint, 1 lb. of minium,

and 2 lbs. of gray oxide of lead; pass the mixture through a sieve and keep it in a powder for use. When wanted for use a sufficient quantity of the powder is mixed with some vegetable oil upon a board or in a trough in the manner of mortar, in the proportion of 605 lbs. of the powder to 5 gallons of linseed, walnut, or pink oil, and the mixture is stirred and trodden upon until it assumes the appearance of moistened sand, when it is ready for use. The cement should be used on the same day that the oil is added, else it will set into a solid mass." (*Bourne.*)

With boilers set on a platform in the above-described manner the cement is apt to crack after a while and become detached from the shell of the boiler, and when leaks occur in the bottom of the boiler the water spreads over the platform and corrosion takes place over a large surface unnoticed. Access to the bottom of the boiler can be had only by cutting away portions of the platform from below, and it is a difficult matter to locate a leak in the bottom of the boiler. For these reasons it is thought preferable to omit the platform and let the boiler rest directly on keelsons, a clear passage, extending the whole length of the boiler, being left between the keelsons, so that the bottom of the boiler may be examined, cleaned, painted, and repaired. The boiler should be placed so that the seams connecting the front and back to the bottom are accessible for calking, and for removing and replacing rivets. Boilers must never be set directly on oak or other wood containing acids which corrode iron, but a cap-piece of pine must be spiked to the top of the keelson.

The water-legs of dry-bottom boilers are set on cast-iron frames or saddles. Figures 3 and 4, Plate XXXI., illustrate the form of saddles used in United States naval vessels. The ashpan and half of the saddles for the sides and back of each furnace are frequently cast in one piece. When they are made in separate pieces they are more easily handled in case it is necessary to remove them for the purpose of examining or repairing the water-legs without moving the boiler from its seat. At places where laps or rivets occur on the water-legs the top flange of the saddle is cored out to clear them. All spaces between the water-leg and the upper flange of the saddle are filled with cement, so that no water can lodge there. When dry-bottom boilers are used in a wooden vessel precautions have to be taken to prevent the keelsons and the lining of the vessel being set on fire by the heat radiated through the interstices of the grates or by the fire which falls in cleaning or hauling the fires. In several United States naval vessels the wooden keelsons are protected by cast-iron cap-pieces on which the saddles rest; an air-space is formed under the cast-iron ashpan by corrugated wrought-iron plates, $\frac{1}{8}$ inch thick, resting on the keelsons and on ledges formed on the rib which stiffens the bottom of the ashpan.

The arrangement shown in figure 4, Plate XXXI., was designed for U. S. S. *Yantic.* The bottom of each ashpit is formed by a shallow tank 4 inches deep, built of $\frac{3}{8}$-inch wrought-iron plates and stiffened by $\frac{3}{4}$-inch socket-rivets placed 9 inches apart. This tank is filled with cement, which must be poured in from the side and not from the top. This ashpan rests at its four corners on cast-iron blocks 8 inches square, which are secured by a large wood-screw to the keelsons. The saddles rest on the top of the ashpan on wrought-iron strips, and the sides and the back of the saddles are made in separate pieces. This arrangement allows any of the saddles to be removed and replaced with ease without raising the boiler from its seat; and after removing any of the saddles the corresponding tank on which they rest may likewise be pulled out and replaced.

Cylindrical boilers rest on saddles, as shown on Plate XXX. and in figure 2, Plate XXXI. These saddles are either made of cast-iron or are built up of wrought-iron plates and angle-irons. In wooden vessels they are secured by holding-down bolts to the keelsons; in iron vessels they are frequently riveted to the frames of the hull.

2. Securing Boilers.—To prevent the boilers from shifting or moving in consequence of the violent motions of the vessel in a sea-way, they are securely tied to the hull of the vessel, and when there are several boilers arranged in pairs they are tied at the top to one another. No part of the boilers rigidly connected with the shell should be attached to the decks of the vessel; on the contrary, sufficient clearance must be left between the deck-beams and hatch-framing and the boilers to allow for the working of the ship when it is severely strained. The longitudinal or pitching motion of large vessels is not sufficiently violent to necessitate special precautions for holding flat-bottomed boilers in their seat. To guard against the effect of the transverse or rolling motion of the vessel the boilers are tied down to the floor of the vessel by wrought-iron straps passing diagonally up the sides of the boilers. These straps are secured to the shell by bolts and nuts; the bolts must fit accurately the holes in the straps and in the shell.

When boilers of the type illustrated on Plates VI., VII., and XVII., in which the uptake forms an integral part of the shell, are arranged in pairs opposite to one another, they are sufficiently tied together at the top by their uptakes. When the uptakes are separate structures, built on the shell of the boilers, the latter are generally tied to one another at the top by straps or braces. In U. S. S. *Trenton* each pair of opposite boilers is tied together near the top by two wrought-iron straps, 1 inch thick and 4 inches wide, extending across the fire-room immediately below the uptakes. Each end of these straps is secured to the cylindrical shell of the boilers by four bolts $1\frac{1}{4}$ inches in diameter. The cylindrical boilers of U. S. S. *Nipsic* (see Plate XXX.) are secured to

their saddles by turned bolts passing through reamed holes in the shell; the saddles are held by composition bolts passing through the frames of the hull.

In other vessels each cylindrical boiler is held down in the saddles by four wrought-iron braces, one being placed near the front and another near the back at either side of the boiler. The lower end of each brace is bolted either directly to the hull of the vessel or to the saddle, and the upper end is secured by a nut to a lug bolted to the cylindrical shell of the boiler.

3. Erection of Boilers in the Vessel.—In preparing the bed on which the boilers or their saddles are to rest, the boiler-keelsons are dubbed off to lines marked on their sides representing the intersections of the plane of the bottom of the boilers or their saddles with the keelsons. To find the traces of this plane stretch two lines, one at the after end and one at the forward end of the boiler-bed, at a determined height above the top of the main keelson, and at right angles with the horizontal centre line of the main keelson and with perpendiculars drawn from the centre line of the deck to the centre line of the main keelson; then measure from the transverse lines the distance at which the bottom of the boilers or their saddles should be placed below the horizontal plane passing through these two transverse lines, and mark the points thus found on the sides of the boiler-keelsons.

In case the boilers are to be set on a platform allowance is to be made for the thickness of the planking and of the bed of cement, and the platform is built on the keelsons after these have been dubbed off to the proper height.

The distance of the centre line of the boilers from the centre line of the engines is measured along the centre line of the main keelson according to the dimensions given on the drawing, and is marked on the keelsons by a transverse line perpendicular to the centre line of the main keelson. The location of each boiler is then determined by measuring the distances given on the drawing from the centre line of the main keelson and from the common centre line of the boilers, and the points thus found are marked on the boiler-keelsons or the platform.

In case saddles are used for the boilers, they are now placed in position.

After these preparations are made the boilers are put aboard by means of a crane or shears. When the boilers are slung in chains the corners of the shell must be protected by chafing-gear of wood and mats. The boilers are put aboard without the furnace and uptake doors, grate-bars, valves, and other removable attachments; but it is well to keep the manholes and handholes and similar openings closed, in order that if the slings should give way and the boiler should fall overboard it would not fill with water.

The decks are left open sufficiently to allow the boilers to pass through them; and the deck-framing around the boiler-hatches is arranged in such a manner that it can be taken up without disturbing the deck-beams when the boilers are to be hoisted out at a future time.

The first boilers to be put aboard are those which are to be situated at the extreme forward and after ends of the fire-room. As the boiler is lowered down into the hold of the vessel it is placed on blocks or rollers; the slings passing around the shell are then cast off, and the boiler is moved by means of tackle, jacks, or other appliances into its proper position corresponding to the marks on the keelsons, and then it is gradually lowered from the blocks into its seat. The correctness of the position of boilers of the type represented on Plates VI., VII., XVII. is verified by seeing that the upper portions of the uptakes, which form the base of the chimney, meet properly, and that the centre of the circle formed by their cross-section falls on a line stretched from the centre of the boiler-hatch to the centre line of the main keelson.

When the boilers are to be set in cement on a platform, they must now be raised by jacks from their seat sufficiently high to allow men to crawl under them and spread the cement evenly over the platform; during this process the boilers are supported at the four corners by blocks of wood. After the bed of cement has been laid the boilers are lowered carefully into position.

Boilers which are to rest on saddles are first placed on blocking directly over their saddles; after the correctness of their position relatively to each other and to their saddles has been verified they are lowered carefully into their seat.

The straps which are to tie the boilers to the hull of the vessel and to one another are now fitted and secured to them, and the uptakes which are built in the boilers are riveted together where they meet at the top. With cylindrical boilers the construction of the smoke-boxes and uptakes commences now. The grates, doors, valves, and other fixtures are attached to the boilers as soon as these are placed permanently in position. The pipes connecting the boilers with the outboard-valves, the pumps, and the main engines are next put up; the exact length, shape, and position of these pipes is determined by making board templates after the boilers are placed in position, care being taken that the cocks and valves attached to them are accessible, that one pipe may be taken down without removing another one, that the bends of the pipes form easy curves, and that the pipes follow the most direct course compatible with the foregoing conditions.

Finally, the felting and other covering is placed over the boiler-shells and the pipes.

As soon as the uptakes are constructed, and the deck around the boiler-hatch has been completed, the chimney and the escape-pipe are hoisted aboard and placed in position, and the hatch-gratings, plates, ventilators, etc., are put up. In slinging the smoke-pipe for hoisting it must be stiffened by temporary wooden stays placed inside, or by boards placed outside between the slings and the pipe.

CHAPTER XV.

BOILER MOUNTINGS AND ATTACHMENTS.

1. Grate.—The grate of furnaces in which coal is burnt is composed of alternate bars and spaces.

In many boilers the front part of the grate is formed by a horizontal or slightly inclined iron plate without perforations, about 20 inches long; this is called the *dead-plate* or *dumb-plate.* It was introduced by Watt, and is used especially in furnaces where bituminous coal is used as fuel. In firing the coal is thrown first on the dead-plate, where the radiant heat of the fire volatilizes the hydrocarbons; and after the coal is thus reduced to coke it is pushed inwards and spread over the fire. In the boilers of United States naval vessels the dead-plate is omitted.

The *grate-bars* are ordinarily placed lengthwise the furnace and rest on supports at the front and back of the furnace, and, when the grate is long, on one or two intermediate cross-bars. The bars must be strong enough to bear the weight of the fuel and to withstand the rough usage to which they are unavoidably subjected in working the fire. They must rest securely on their supports, but must be allowed to expand and contract freely with the great variations of temperature to which they are exposed.

The overheating of the bars is prevented by the rapid currents of air rushing to the bed of fuel through the spaces between the bars, and by a thin layer of ashes accumulating on the top of the bars. The overheating of bars may be due to their faulty form, or to obstructions in the spaces preventing the free inflow of air, or to the intensity of the fire; in such cases the bars will bend and warp and partially melt on the top.

Coals containing sulphur or forming easily-fused clinker destroy the bars rapidly; the clinker sticks between the bars and obstructs the air-passages.

The top of the grate should always form a level surface flush with the bottom of the opening of the furnace-door; the bars which project above the level of the grate are liable to be burnt and to be displaced in working the fire.

Grate-bars have been made hollow to allow a current of air or water to pass through them, for the purpose of increasing their durability and adding to the efficiency of the

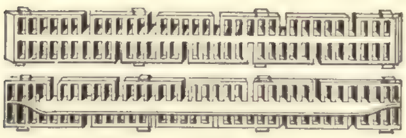
furnace; but the cost of such contrivances and the difficulty of keeping them in order have caused their rejection.

In marine boilers the grate generally slopes downward from the furnace-mouth to the bridge-wall. By this means the back of the grate is more easily kept covered with fuel, and the coal is prevented in a measure from falling out of the furnace into the fire-room when the ship rolls and the door is open. The rate of this slope varies from one in ten to one in twenty, and is limited by the heights required over the top of the grate at the furnace-mouth for proper firing, and below the grate at the bridge for admitting a sufficient amount of air and for working the fire from the ashpit.

Grate-bars are usually made of cast-iron. Wrought-iron bars are frequently used in the boilers of locomotives, and are also not unfrequently used in marine boilers; they bend and warp easily, but can be straightened; they are not so easily broken or fused and burnt as cast-iron bars, and they may be made somewhat lighter than the latter. For these reasons wrought-iron bars are probably cheaper in the end, although their first cost is greater than that of cast-iron bars. Wrought-iron bars are most simply made by riveting two plain bars together, with thimbles between them for distance-pieces at the ends and in the middle, and letting the heads of the rivets determine the width of the space between two adjacent double bars.

The length of grate-bars should not much exceed three feet. According to Ledieu, the grate-bars of French naval boilers are usually made of wrought-iron, and 29½ inches or 21½ inches long, according to the length of the grate. Short bars are more easily handled than long ones, and are twisted less out of shape by overheating.

Fig. 133.



Various shapes have been given to grate-bars mainly with a view to increase their durability. Figure 133 represents the top and bottom views of a grate-bar in common use, designed to be free from a tendency to warp on account of its peculiar shape.

The cast-iron bars generally used in United States naval boilers are illustrated on Plate XIX. These grate-bars are usually made from ⅝ inch to ¾ inch wide on the top. At the bottom they should be made as thin as they can be cast, and the necessary strength should be obtained by proportioning their depth to their length. Thin and deep bars are less liable to warping than thicker and less deep bars, because the inflowing air abstracts the heat more readily from them. Grate-bars are generally made from ¼ inch to ⅜ inch thick at the bottom, and from 3 inches to 3¾ inches deep in the middle of their length. The outline of the bottom has approximately the form of a parabola.

Grate-bars have sometimes a uniform width for a depth of about $\frac{3}{4}$ inch from the top, and below that depth a rib of diminished but uniform thickness; it is, however, preferable to let them taper evenly from the top to the bottom, as such a form facilitates the flow of air to the fuel, the fall of refuse matter through the grate, and the pricking of the fire from below.

At each side of the ends of the bars projections are formed which determine the width of the spaces between them. When the length of bars exceeds 30 inches similar projections are formed midway between their ends to increase their lateral stiffness. Grate-bars are generally made double, so that two bars with the proper space between them form one piece; this saves time in removing and replacing them, and increases greatly their stiffness. A number of single bars are provided with the double bars, so that the whole width of the furnaces may be filled by the bars without jamming them and with the proper spaces between them.

The following considerations govern the width of the spaces between the bars: a sufficient quantity of air must be admitted to the fuel; the spaces must not be obstructed too easily by clinkers; the prick-bar must pass through them to free the bottom of the bed of fuel from ashes; on the other hand, the coal used as fuel must not drop through them, therefore small, free-burning coal requires narrower spaces than lump coal and caking coal. The width of the clear space between two bars is usually $\frac{7}{16}$ inch or $\frac{1}{2}$ inch when good semi-bituminous coal is used; with anthracite, and with coals that cake much or yield large quantities of ash and clinker, the space is made $\frac{5}{8}$ inch wide, and sometimes even more.

All cast-iron bars used in United States naval vessels have a shallow groove on the top; the ashes which accumulate in these grooves prevent clinkers from adhering to the bars, and the latter are less easily burnt.

The grate-bars rest with their ends on cross-bearers or bearing-bars, and they are allowed to expand freely in the direction of their length. The front end of each bar is often provided with a lug at the bottom, which hooks on the bearing-bar and limits the motion of that end of the bar; this lessens the chance of the bar sliding off its seat when it becomes shortened by warping. The space allowed for expansion at the ends of bars is frequently insufficient; it should not be less than the width of the air-spaces between the bars.

To prevent coal or clinker from lodging tightly between the ends of bars the ends are often made slanting, either at the top or at the bottom, instead of square. Sometimes one end of the bars is made tapering and rests on an inclined seat (see Plate XV.); this arrangement allows the bars to expand freely; but the bars are apt to be raised

above the level of the grate, and, in consequence, to be burnt or become displaced in cleaning the fires.

The *bearing-bars* are made either of cast-iron or of wrought-iron, and rest with their ends on lugs attached by bolts to the sides of the furnace (see Plate XIX.)

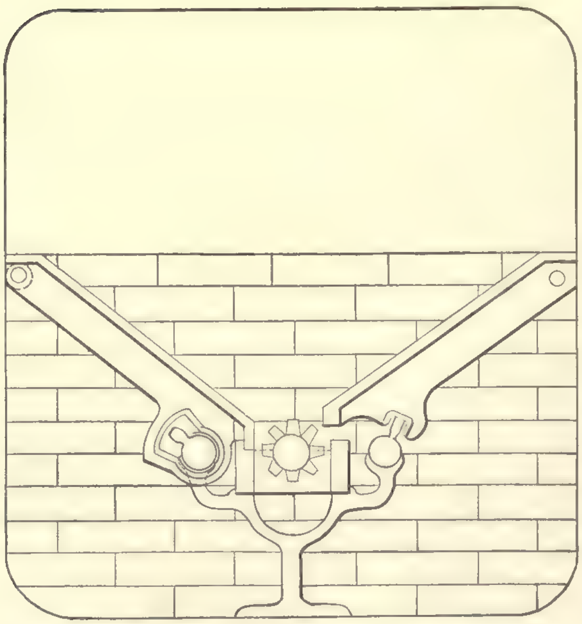
The middle bearing-bar is made double, with a wide space to let ashes and clinker fall through.

The front bearing-bar is secured by a few large bolts to the furnace door-frame; or, when a dead-plate is provided, it serves as a support for the front end of the grate-bars.

The back bearing-bar rests on lugs bolted to the water-bridge, and is provided with a lug at each end in order to maintain an air-space between the bar and the bridge-wall. When the bridge-wall consists of a separate iron frame supporting a wall of fire-brick the back end of the grate-bars rests on a ledge formed on the frame of the bridge-wall.

2. Moving-grates.—In order to diminish the labor of attending to the fires and the loss in efficiency of boilers due to the opening of the furnace-doors for supplying the fuel and cleaning the fires, various contrivances have been made for supplying fuel to furnaces evenly and continuously by mechanism. Circular revolving grates turning slowly about their centre, and grates consisting of an endless web of short bars moving on horizontal rollers, and travelling from the furnace-mouth to the bridge and returning through the ashpit, have been used; but none of these contrivances have been successfully applied to marine boilers.

Fig. 134.



In other forms of moving-grates applied to marine boilers a short, reciprocating motion up and down, or from side to side, may be given to the grate-bars, in order to keep the grate clear of ashes and clinker without opening the furnace-door and using fire-tools.

The *Murphy shaking-grate* (see figure 134) consists of alternate stationary and vibrating bars placed at right angles to the length of the furnace. There are two sets of

bars, forming two inclined planes, sloping downward from the sides of the furnace to the centre. The stationary bars rest with their upper ends against the sides of the furnace and with their lower ends on a cast-iron frame consisting of two parallel bars extending through the length of the furnace, supported by suitable brackets. The vibrating bars are pivoted at their upper ends to the upper ends of the stationary bars, and their lower ends rest against the continuous feather of a horizontal bar lying lengthwise the furnace in pillow-blocks placed at the front and back of the furnace; there are two of these horizontal bars, one for each side of the grate. By rocking the horizontal bar forward and back on its axis by means of a lever attached to the end protruding from the ashpit into the fire-room, the pivoted bars receive a vibrating motion, their lower ends being forced alternately above and below the level of the stationary bars.

At the bottom of the two inclined planes of the grate, and entirely independent of it, is a horizontal bar, 3 inches in diameter, lying lengthwise the furnace in five pillow-blocks attached to the central frame. This bar bristles with eight rows of projecting teeth, forming cubes of one inch a side. This bar may be rocked forward and back, or revolved entirely around its axis, by a lever attached to the end protruding into the fire-room. This is called the clinker-crusher and refuse-remover.

In firing the coal is thrown along the upper ends of the grate-bars solely, and slides downward by gravity over the grate-surface as the coal on the latter is consumed. An occasional shaking of the grate by the vibrating bars accelerates the descent of the coal, removes from it such refuse as can fall between the grate-bars, and prevents the occurrence of holes in the fire. Such of the refuse from the coal as cannot pass through the spaces between the grate-bars slides down the grate-surface by gravity, and is broken up and worked into the ashpit by the vibratory motion of the clinker-crusher. The fires are thus kept clean and free of holes without the employment of fire-tools, and the furnace-doors are only opened for throwing in the coal.

The weight of this grate is about double the weight of the ordinary grate.

Experiments made by a board of United States naval engineers to determine the efficiency of the Murphy grate showed that, compared with the ordinary grate, the economic gain due to its use was in direct proportion to the per centum of refuse removed through the furnace-door with the ordinary grate in use. (*See section* 13, *chapter ii., and* '*Report on the Murphy Grate-bar, by a Board of United States Naval Engineers, June* 25, 1878.')

The *Martin* or *Ashcroft grate* (see figure 135) is formed by wrought-iron bars, 1½ inches square in cross-section, extending the whole length of the furnace and projecting

5 or 6 inches beyond the front of the boiler. These grate-bars rest on wrought-iron bearing-bars placed about 18 inches apart and supported at the ends by lugs bolted to the sides of the furnace. The upper side of the bearing-bars is either bevelled to a knife-edge or it is crenated into semicircles, in which the grate-bars rest and from which they cannot be displaced in turning. The bars are revolved by means of a socket-wrench applied to their ends, and the fire is thus to be cleaned from ash and clinker without opening the furnace-door; but no thorough cleaning of the fires can be made by merely revolving the grate-bars, which by a few turns cut out grooves in the fires and leave the coherent mass above untouched. (*See* '*Report on Ashcroft Furnace-doors and Grate-bars, by a Board of United States Naval Engineers, March* 27, 1878.')

3. Bridge-walls.—The bridge is a wall or partition near the back of the furnace which limits the length of the grate and forms an abutment for the bed of fuel. The height of the bridge-wall regulates the area of the passage leading from the furnace to the combustion-chamber or back-connection, and affects greatly the efficiency of boilers, through the influence which it exerts on the amount of air admitted to the furnace and on the thorough mixing of the gases during combustion. (*See section* 5, *chapter vii.*)

The bridge is often formed by a hollow wall communicating with the water-space of the boiler and forming an integral part of the latter (see section 7, chapter ix.), or it is formed by a wall of fire-brick. Sometimes a solid mass of fire-brick fills the back of the furnace behind the grate; but this arrangement is objectionable, because it hides leaks which may occur there. The bridge-wall consists usually of a vertical cast-iron frame resting on the bottom and bolted by means of flanges or straps to the sides of the furnace, or of a horizontal plate extending from the back of the grate to the back of the furnace, and resting on brackets or angle-irons bolted to the sides of the furnace; this frame or plate supports the back end of the grate-bars and, behind them, a wall of fire-brick (see Plate XII.)

The bridge-wall is often provided with openings for admitting jets of air to the combustion-chamber or back-connection, the supply of air being regulated by a register or by a hinged valve, the position of which can be adjusted by means of a rod and suitable connections from the fire-room (see Plate XV.) Such openings in the bridge-wall are now always omitted in the boilers of United States naval vessels, since repeated experiments have demonstrated that an air-admission to the back-connection produces no useful results when anthracite coal is used as fuel. In English and French boilers designed to burn bituminous coal the bridge-wall is always provided with openings for air-admission. Specifications issued by the Admiralty for boilers for English naval vessels require an aggregate area of not less than three square inches of opening in the bridge

for the admission of air to the back-connection for each square foot of grate-surface. (*See section* 11, *chapter vii.*)

4. Furnace-doors and Door-frames.—The furnace-door opening in marine boilers having grates of the usual dimensions is ordinarily from 14 inches to 16 inches high and from 18 inches to 20 inches wide, the upper part being arched and the lower part square.

In the rectangular boilers of United States naval vessels the furnace-door openings are constructed in the front wall of the boiler in the manner shown on Plates VI., VII., and XVII. When cast-iron furnace-doors are used the opening is surrounded by a cast-iron frame bolted by five or six ⅞-inch bolts to the boiler-front. On this frame are cast the catch and the hinges for the door and the sill-plate; the frame is fitted to the boiler-front by means of a narrow chipping-strip surrounding its outer circumference, and around the door-opening it has another chipping-strip, against which the door is fitted.

When the furnace-doors are made of wrought-iron, door-frames are dispensed with, the doors being made to fit directly against the boiler-front and the sill-plate. The latter is made either of wrought-iron or cast-iron, and is bolted in place as shown on Plate XIX. The top of the sill-plate is level with the top of the front of the grate, and it has a flange to which the front bearing-bar is bolted or riveted.

When the furnace is secured to the boiler-front in the manner shown in figure 96 and on Plates VIII., XI., and XII., a frame is bolted in the furnace-mouth, to which the furnace-door is fitted (see Plate XXIX.) This frame consists of a single casting about 6 inches deep, to which at the front and back wrought-iron plates ⅜ inch thick are bolted, thus forming a double wall which intercepts the heat radiated from the incandescent fuel. The front plate is provided with a few holes about 1 inch in diameter, and the back plate is perforated with numerous holes ¼ inch or $\frac{3}{16}$ inch in diameter. The catch and hinges for the furnace-door are riveted to the front plate of the door-frame.

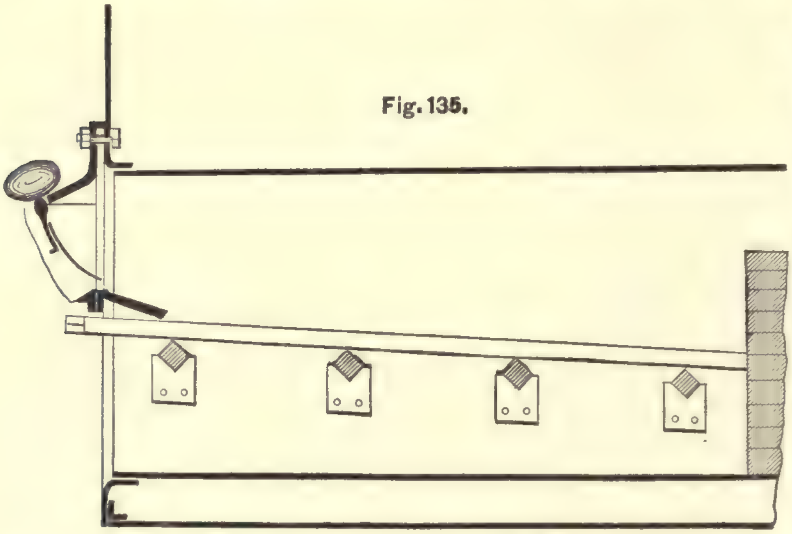
The wrought-iron furnace-doors of boilers of United States naval vessels consist of a front plate provided with about fifteen 1-inch holes, and stiffened by a lip turned up around its circumference which fits against the boiler-front; and of a back plate, which has flanges about 2½ inches deep turned up around its circumference, and is perforated with numerous ¼-inch or $\frac{3}{16}$-inch holes. The two plates are made of ¼-inch boiler-iron, and are tied together by four ⅞-inch socket-rivets (see Plates XIX. and XXIX.)

Cast-iron furnace-doors have a similar box-form; the front and sides are cast in one piece about ½ inch thick, and a wrought-iron or cast-iron screen-plate, perforated with

numerous small holes, is bolted to the back, lugs being cast on the sides for securing it. The hinges are cast on the front plate, which is also provided with a number of large holes for the admission of air. The hinges of furnace-doors are made frequently of composition.

The *Martin* or *Ashcroft* furnace-door (see figure 135), which has been fitted to a number of boilers of United States naval vessels, consists of a square wrought-iron plate, slightly concave on the inward side, which is hung from a horizontal axis fixed to the upper edge of the door. This axis rests on brackets attached to the cast-iron furnace door-frame at each side of the furnace-mouth, and is provided with counterbalances which are to keep the door in any position in which it may be placed. After a series of competitive trials with the Martin door and the ordinary furnace-door, the former was condemned by a board of naval engineers as possessing none of the practical and economical advantages claimed by the patentee, and offering, on the contrary, serious inconveniences in managing the fires. (*See* '*Report on Ashcroft Furnace-door and Grate-bar by a Board of United States Naval Engineers.*')

Fig. 135.



In order to intercept more completely the heat radiated from the bed of incandescent fuel and communicate it to the entering air, several sheets of wire gauze have sometimes been placed between the perforated front and back plates of the furnace-door.

"The most complete apparatus for intercepting the heat radiated to the furnace-door is that of Mr. Prideaux, which consists of three gratings, each made of a series of thin iron plates set edgeways, with narrow passages between them for the entering streams of air. The radiant heat is completely intercepted by placing two of those sets of plates with opposite obliquities, and the third parallel to the sides of the furnace mouth-piece." (*Rankine.*)

To regulate the admission of air through the door to the furnace Prideaux made the

gratings movable like Venetian blinds; a self-acting mechanism opened them when fresh coal was supplied, and gradually closed them as the fuel became converted into coke. The openings in the ordinary furnace-door are frequently provided with a register, by means of which the air-admission can be regulated by hand.

According to Rankine the total area of the perforations in the furnace-door, in recent English examples, is $\frac{1}{36}$ of the area of the grate when 25 pounds of bituminous coal are burnt per square foot of grate per hour. In United States naval boilers, burning from 12 to 16 pounds of anthracite per square foot of grate per hour, the aggregate area of the openings in the furnace-doors varies between $\frac{1}{2}$ square inch and 1 square inch per square foot of grate.

5. Connection-doors, Ashpit-doors, and Ashpans.—Cast-iron connection-doors are at present superseded by wrought-iron ones, which are fitted without door-frames directly to the front of the boiler. The hinges are often made of composition, and are placed either at the top or at one side of the door.

To diminish the radiation of heat from the large surfaces of these doors a shield-plate is secured to the door-plate by means of socket-rivets, leaving a space of two or three inches between the two plates. This shield-plate is placed either on the inside or the outside of the door-plate, and in some cases two shield-plates, an inner and an outer one, are employed.

The connection-doors of United States naval boilers (see Plates XIX. and XXIX.) are made double, of $\frac{1}{4}$-inch plate-iron, stayed by socket-bolts; the outer plate is stiffened by a lip turned up around its circumference, the edge of which fits closely against the front of the boiler; the edges of the inner flanged plate form a well-fitting joint on the outer plate. The space between the two plates is sometimes filled with a non-conducting material, as plaster-of-Paris, but this makes the door heavy. On this account the dead air in the space is generally relied on as a non-conductor.

Ashpit-doors are used to check the draught in order to diminish the rate of combustion, and to prevent the inflow of cold air through furnaces which are not in use. They should be made to fit close and to be easily opened and shut.

Sometimes the door consists of a simple plate placed in the mouth of the ashpit, which turns on a horizontal axis passing through the middle of the plate (like a damper), catches being provided to secure the plate in any desired position.

Wrought-iron or cast-iron doors, opening in halves and hinged on either side of the ashpit, are frequently used. In such cases a cast-iron or angle-iron frame is secured by bolts to the boiler-front around the ashpit-opening, and the doors are provided with openings and a register for regulating the admission of small quantities of air to the

ashpit. Such hinged doors are generally used when air is forced into the ashpits by means of a fan-blower.

In boilers of United States naval vessels the ashpit-doors are now made always of a single wrought-iron plate, $\frac{1}{8}$ inch or $\frac{3}{16}$ inch thick, stiffened by a lip turned up around its circumference. The edge of this lip fits directly against the front of the boiler. The construction and manner of securing these doors are illustrated on Plates XIX. and XXIX. When the ashpits are to be kept wide open the doors are lifted off their catches and hung upon hooks permanently attached to the connection-doors.

In dry-bottom boilers cast-iron or wrought-iron *ashpans* are used which are removable and are intended to contain water. Wrought-iron ashpans are made of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch iron, of a single plate, with a flange turned up around the sides and back. The front slopes gradually up to the height of the flange to facilitate the hauling of the ashes. The bottom of the pans may be stiffened by two or three angle-irons running in a longitudinal direction.

False ashpans are sometimes used to protect the iron and the stay-bolt heads of water-bottoms from the corroding effect of wet ashes and from rough usage in hauling ashes. They are made of wrought-iron, having a lip a couple of inches high turned up on each side, and in front a lip turned down which laps over the ledge of the floor-plates.

6. Manhole and Handhole Plates.—Manholes giving access to the interior of the boiler are cut in the front of the boiler in the spandrels between the furnaces, besides one or two near the top of the boiler leading into the steam-space.

Handholes or mudholes are cut in the water-legs near the bottom in the front and back of the boiler, and at other convenient places, for scaling, cleaning, and washing out the boiler.

Manhole and handhole plates should always be put on the inside of the boiler, so that the steam-pressure tends to tighten the joint and keep the plate in position in case the threads of the bolts which secure the plates should be stripped.

Manholes and handholes are generally made oval in shape, of such proportions that the smallest diameter of the plate is somewhat less than the largest diameter of the hole. Where practicable the largest and smallest diameters of manholes are made about 15 inches and 12 inches respectively. When the space in the spandrels between the furnaces does not admit of cutting oval holes of sufficiently large size the holes are often triangular in shape. In cylindrical shells manholes should be cut in such a way that their shorter axis lies in the longitudinal direction of the shell, so that the least quantity of metal is removed in the line where the greatest strain obtains.

A flat, welded wrought-iron ring, about 3 inches wide, is riveted around manholes

inside the boiler and calked tight, the rivet-heads being countersunk. The practice of putting this ring outside the boiler, prevailing still to a great extent in England, is wrong; for the ring gives not only stiffness to the boiler-plate but protects it inside the boiler from corrosion, which is often very active in the vicinity of manholes and mudholes. Cast-iron rings are sometimes used instead of wrought-iron ones; but especially on cylindrical shells, where these rings have to restore the strength lost by cutting the openings, cast-iron rings do not answer the purpose on account of the difference of elasticity of cast-iron and wrought-iron under a tensile strain.

The following example will illustrate the manner in which the proper size of strengthening-rings of manholes in cylindrical shells may be determined: Suppose the cylindrical shell of a boiler to be $\frac{1}{2}$ inch thick, and a manhole 15 inches by 12 inches to be cut in it, with the longer axis in the circumferential direction of the boiler. The weak places near such a hole lie in the longitudinal axis of the boiler, and there have been removed from the shell $(12 \times \frac{1}{2} =)$ 6 square inches of metal in the line of this axis. To make this part of the shell as strong as the longitudinal joint of the shell the quantity of metal added by the ring surrounding the manhole should be equal to about 65 per cent. of the metal cut away, and, consequently, the cross-section of the ring at each end of the hole should be $\left(\frac{6 \times 0.65}{2} =\right)$ 1.95 square inches. Making the ring $\frac{3}{4}$ inch thick, its least width should be $3\frac{5}{8}$ inches, if $\frac{7}{8}$ inch is allowed for the rivet-holes.

In English and French boilers the strengthening-rings around manholes are often made of angle-iron, being in such a case riveted to the outside of the boiler. This has the advantage that the largest amount of metal is concentrated where the strain on the plate is most severe, and rupture would commence, and the greatest stiffness is required —viz., at the edge of the hole. On the boiler represented on Plate XV. the rings around the manholes on the ends of the boiler are made of angle-iron $3'' \times 3'' \times \frac{5}{8}''$.

The manhole-plates are usually made of cast-iron, the larger sizes being about $1\frac{1}{8}$ inches or $1\frac{1}{4}$ inches thick. They have generally a dished form, the convex side being inside the boiler—this form being best calculated to resist the strains on the plates without buckling. They are secured to the boiler by one or two wrought-iron bolts passing through cross-bars which straddle the hole outside the boiler. These cross-bars are now also generally made of wrought-iron. The bolts are generally secured permanently to the plate by a countersunk riveted head. Large plates are provided with a wrought-iron handle screwed into a boss in the centre of the plate. The plate, bolts, and cross-bars must be made sufficiently strong and stiff to bear with safety and without springing the great strains thrown upon them in screwing up the plate. The bolts are

made with a coarse thread, and square nuts should be used, because the corners of hexagonal nuts are liable to become rounded when the wrench does not fit well.

Instead of fitting the flange of a manhole-plate directly to the cylindrical shell of a boiler, as in figure 5, Plate XXXI. (which requires very careful work), the stiffening-ring inside the boiler sometimes forms a plane seat for the flange of the plate; or, when the radius of the curved surface is small, a casting is riveted to the outside of the boiler around the manhole, having a flange which forms a plane seat for the plate (see figure 136).

In order to reduce the weight of large manhole-plates they are sometimes made of wrought-iron. Figure 137 represents the wrought-iron manhole-cover of a boiler de-

Fig. 136.

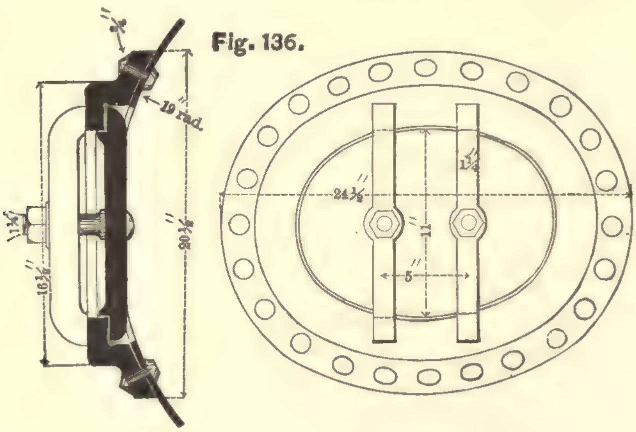
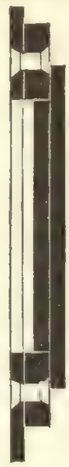


Fig. 137.



signed for a working pressure of 70 lbs., built by Maudslay Sons & Field (England) in 1873. The dimensions of the manhole are 15 inches × 10 inches, and its shape is rectangular with rounded corners. Two plates $\frac{3}{4}$ inch thick are riveted together with countersunk rivets. The outer plate is of the size of the hole, while the inner plate is large enough to form the flange $1\frac{1}{4}$ inches wide. The bolts are screwed into the plate, the ends being riveted over. The ring around the hole is 1 inch thick and $2\frac{7}{8}$ inches wide, secured by countersunk rivets to the shell, which is $\frac{1}{2}$ inch thick.

Wrought-iron plates made of a dished form by pressing them with a die of suitable shape into a mould would be much stiffer than flat plates, and could be made proportionately thinner.

Figures 1 and 5, Plate XXXI., represent the manhole-covers made recently for United States naval boilers. They are cast of old composition metal consisting of 88

parts of copper, 10 parts of tin, and 2 parts of zinc. The wrought-iron bolts are secured in the plates by riveting over the ends, which pass through accurately-drilled holes. A handle is cast on the plate.

7. Steam Stop-valves, Dry-pipes, and Steam-pipes.—The stop-valves of boilers must be arranged in such a manner that they are easily accessible and can be opened and closed quickly. Each boiler must have a stop-valve, bolted directly to the shell, to shut off all communication between the boiler and the steam-pipe connected with the engines or the other boilers. In case there are separate steam-drums or superheating-chambers the stop-valves and connecting steam-pipes must be arranged in such a way that any one of the boilers or steam-chambers may be shut off without the necessity of putting any of the others out of use.

It is a safe rule to make the area of stop-valves and steam-pipes sufficiently large that the velocity of the steam passing through them does not exceed 100 *feet per second* when the speed of the engines is a maximum.

Figures 1 and 2, Plate XXXII., represent the stop-valves of the boilers of the U. S. S. *Nipsic*, and may serve to illustrate the usual construction of these valves for United States naval boilers. When the valves are large the chamber is made of cast-iron, and a valve-seat, made of composition metal, is fitted in it and secured by riveting over the lower end. For smaller valves the whole chamber is made of composition. The valve-disc is made of composition and of a *dished* form to increase its stiffness, and it has a conical seat. It is guided by a central spindle below, working easily in a sleeve connected by ribs to the valve-seat. The wrought-iron stem has a square screw-thread, which works in a corresponding thread cut in a cross-bar supported by wrought-iron studs on the cover of the valve-chamber. The stem must not be rigidly attached to the valve-disc, so that the latter does not turn with the stem and seats itself always exactly. In the valves represented on Plate XXXII. the stem passes through the valve-disc and its lower end forms the guide-spindle. In other cases the guide-spindle is cast on the valve-disc, and the stem has a collar at its lower end which fits in a recess formed in a projection on the top of the valve-disc; it is held in place by an annular nut screwed to this projection on the valve-disc and secured by a pin.

The stop-valve and steam-pipe must take the steam from the highest part of the boiler, where it is in the driest state. When the boiler has no vertical steam-drum the stop-valve is generally connected with a *dry-pipe*, which draws the steam evenly from a large area within the boiler, and separates to some extent the water which is carried along with the steam from the latter. The dry-pipe extends through the length of the boiler close to the top, and in large rectangular boilers has several lateral branches. It

is connected at one end with the stop-valve chamber by a tight joint, while its other end is closed. On the top it is perforated by numerous evenly-spaced holes of about $\frac{3}{8}$ inch diameter, or has narrow, transverse slits cut into it by means of a saw. The aggregate area of these openings should be at least double the area of the cross-section of the pipe.

The dry-pipe is often made of cast or wrought iron, but sheet-brass is a preferable material, since the pipe is much exposed to corrosion.

Dry-pipes are frequently omitted because they make the interior of the boiler less accessible; in such cases the opening in the shell is often protected by deflecting-plates or by a box perforated with numerous holes, in order to throw off any water carried up by foaming. When a boiler foams because the area of the stop-valve is too small, and it is not convenient to fit dry-pipes within the boiler, it is better to place an additional stop-valve on the boiler at some distance from the original one than to enlarge the existing stop-valve.

The *steam-pipe* should have as direct a course and as few bends as possible. Expansion-joints must be provided between rigid attachments of the pipe, unless there are bends which will allow the pipe to spring as it expands or contracts in the direction of its length.

Copper pipes, tinned inside and outside and fitted with composition flanges, are generally used for the steam-pipes of United States naval boilers. Cast-iron pipes are far cheaper, but are heavier, and, from the unyielding nature of the material, liable to break when the ship works much or in case the boilers should move in their seats. Wrought-iron pipes, either lap-welded or riveted, are used, but have the disadvantage of being speedily attacked by corrosion.

Drain-pipes must be fitted to all valve-chambers and to all parts of the steam-pipes where water is liable to accumulate.

The arrangement of the steam-pipes and stop-valves of the boilers of the U. S. S. *Nipsic* is shown on Plate XXX.

A stop-valve is bolted to the outboard end of each boiler, connected with a dry-pipe extending through the length of the boiler. These stop-valves (see figure 1, Plate XXXII.) are operated by means of a hand-wheel from below. The stem is continued through the top of the valve-chamber, and over each valve a small hole is cut in the deck, which is ordinarily kept closed by a composition cap. This arrangement makes it possible to operate the valves from the main deck by means of a socket-wrench in case the passage at the back of the boilers should be inaccessible.

A copper pipe, 6 inches in diameter, No. 13 B. W. G. thick, tinned inside and out-

side, is bolted by means of composition flanges $\frac{13}{16}$ inch thick to a nozzle on the stop-valve, and connects each wing boiler with the nearest horizontal steam-drum above it, the middle boiler being similarly connected to either drum. A composition casting, having suitable nozzles for connecting with the steam-pipes, is bolted to the bottom of each steam-drum, and has at its lowest point a nozzle, 3 inches in diameter, to which a drain-pipe is attached which leads to a water-trap.

The inboard end of each drum is connected by means of a short wrought-iron nozzle with the superheating steam-pipe passing through the length of the uptake at either side of the vessel. These superheating-pipes are of wrought-iron, lap-welded. They are 9 inches in diameter, 0.344 inch thick, and have wrought-iron flanges 1 inch thick riveted to them. The nozzles connecting the drums with the superheating-pipes are riveted to the latter. Each superheating-pipe is made in two lengths; the flanges connecting them are surrounded by an iron casing which protects the joint from the heat of the uptake. A safety-valve is attached to the forward end, and a stop-valve $9\frac{1}{2}$ inches in diameter (see figure 2, Plate XXXII.) is attached to the after end of each superheating-pipe. A copper pipe, $8\frac{1}{2}$ inches in diameter, No. 12 B. W. G. thick, bolted by means of a composition flange $\frac{7}{8}$ inch thick to a nozzle of the valve-chamber, conveys the steam from the boilers to the engines.

Each forward and after wing boiler at either side of the vessel is connected by means of a stop-valve, $4\frac{5}{8}$ inches in diameter and bolted to the cylindrical shell of the boiler, with a copper pipe leading over the top of the boilers to the auxiliary pumps and to the distiller.

The steam-pipes and stop-valves for the United States ironclad *Miantonomoh* and class are described in the specifications of the boilers of these vessels in section 10, chapter vii.

8. Check-valves and Feed-pipes.—A *check-valve*, consisting of a disc-valve with a conical seat, is placed between the feed-pipe and the boiler. The valve is kept closed by the pressure within the boiler acting on its upper surface, and rises with each stroke of the pump as the water-pressure within the feed-pipe, acting on the lower surface of the valve, exceeds the boiler-pressure. A detached stem with a square thread bears, when it is screwed down, on the upper surface of the valve and keeps it closed, and when raised regulates the lift of the valve, and consequently the supply of feed-water to the boiler. For guiding the valve it is provided below its seat with three or four wings, or with a central spindle working in a sleeve, and above by a spindle working in a socket in the enlarged end of the detached stem.

When check-valves have much lift the hammering action of the valve causes

the rapid destruction of the valve and seat, so far as tightness is concerned, especially with a quick-acting pump. The lift of a check-valve should not exceed ordinarily $\frac{1}{2}$ inch; and the area of the valve should be such that with this lift the rate of flow of the feed-water through the valve-opening does not exceed 600 feet per minute.

Since much trouble is caused by check-valves leaking or not closing properly when foreign matter lodges between the valve and its seat, a stop-valve is frequently placed between the check-valve and the boiler, which permits the communication between the boiler and check-valve to be cut off for the purpose of examining and cleaning the latter. This stop-valve is also used for regulating the supply of feed-water to the boiler.

In such a case the upper spindle of the check-valve is sometimes continued through the chest-cover, and carries a weight on its top which is sufficiently heavy to overcome the friction of the stem in the stuffing-box and ensures the prompt seating of the valve after each stroke of the pump.

Plug-cocks are preferred by many engineers to screw stop-valves on feed-pipes, because the latter may be prevented from shutting by some solid matter getting under the valve-disc; but cocks of large dimensions are often very difficult to turn, and a feed-cock which cannot be opened causes much greater inconvenience than a feed-valve which cannot be shut tight.

Figure 3, Plate XXXII., represents the feed and check valves of the boilers of the U. S. S. *Nipsic*. A stop-valve is placed between the boiler and the check-valve, and a like stop-valve is placed between the check-valve and the feed-pipe. These three valves have all an opening $2\frac{1}{2}$ inches in diameter, and are contained in a single casting made of composition metal. The stem of the stop-valves is made of steel. The upper guide-sleeve of the check-valve is cast on the cover of the chamber, and the cover is held down by a single bolt passing through a wrought-iron bail.

The check-valve chamber is bolted directly to the shell of the boiler at such a place where it is most conveniently situated for controlling the feed-supply. It is generally placed on or near the front of the boiler at about the height of the furnace-crown, and discharges the water directly into the boiler. It is objected to this arrangement that the comparatively cold feed-water causes injury by impinging directly against the most highly heated part of the boiler. On this account an internal pipe is sometimes provided which leads downward, discharging the feed-water near the bottom of the boiler. In other instances this internal pipe leads upward, discharging the water near the smoke-connection, where the temperature of the gases is least; with the latter arrangement the cool feed-water, sinking by gravity, promotes also the circulation of the water

in the boiler. In some cases the internal pipe, continued horizontally across the smoke-box end of the tubes, has been provided with numerous small openings throughout its length, through which the feed-water is distributed over a wide space instead of being discharged in a mass at one point.

The feed-pipes for United States naval boilers are generally either cast of composition metal or are made of drawn-brass tubes connected by composition flanges and heavily tinned on the inside. Copper pipes have been abandoned on account of the galvanic action produced in the boiler by the small particles of copper abraded and carried along by the feed-water. Cast-iron pipes are heavy and become soon perforated with small holes.

The feed-pipes must be made with as few bends as possible; when they are long they must be provided with slip-joints. The feed-pipes must be placed where they are easily examined and repaired.

The usual arrangement of the feed-pipes in United States naval vessels may be seen on Plate XXX., illustrating the boilers of the U. S. S. *Nipsic.* A feed-pipe, made of composition and having 3 inches internal diameter, runs along the front of the boilers at either side of the vessel below the fire-room floor; and it is connected by vertical branch-pipes, having an internal diameter of 2½ inches, with the check-valve chamber of each boiler.

See section 10, chapter vii., for the specifications of the feed-pipes and check-valves of the boilers of the United States iron-clad *Miantonomoh* and class.

9. Blow-valves and Pipes.—While marine boilers were worked with very low steam-pressure, pumps were used to withdraw continuously a certain quantity of the concentrated water from the boiler, so as to maintain the saturation within the boiler at a given point. But these *brine-pumps* have gone out of use, and the water is blown from the boiler overboard directly by the steam-pressure, the quantity thus blown out being regulated by the opening of the *blow-valves* provided for the purpose.

The blow-valves of United States naval boilers are generally disc-valves with a conical seat, operated by means of a screw-thread cut on the stem of the valve; the valves and valve-chambers are made of composition metal, and are similar in construction to the stop and feed valves represented on Plate XXXII. It is urged against the use of disc-valves that small chips, pieces of incrustation, or other solid matter are liable to lodge on the seat of such valves and prevent their closing tight when to all outward appearance they may seem quite shut. On this account cocks are preferred by many engineers for blow-valves.

The principal drawback to the use of large cocks is their liability to stick fast in

consequence of corrosion or incrustation, of unequal expansion of the plug and shell, or of other causes producing excessive friction. The tendency to stick fast is greatly aggravated when the shell is made of cast-iron and the plug of brass; both should be made of composition metal, not too soft. "For pressures of 20 or 30 lbs. a taper of *one* in *four* is found to work well, but for pressures of 90 or 100 lbs. a taper of *one* in *six* is necessary to ensure tightness." (*Wilson.*)

The regulations of the Board of Trade (English) prescribe that—

"All blow-off cocks and sea-connections are to be fitted with a guard over the plug, with a feather-way in the same, and a key on the spanner, so that the spanner cannot be taken out unless the plug or cock is closed. One cock is to be fitted to the boiler, and another cock on the skin of the ship or on the side of the Kingston valve."

The chamber of the blow-valve is bolted directly to the shell of the boiler in a convenient position on or near the front of the boiler.

The *bottom blow-valve* is used, while the boiler is in operation, to remove the dirt and sediment which collects in the bottom of the boiler by discharging a limited quantity of water at intervals, and to fill the boiler with water from the sea before starting the fires, and to empty the boiler after hauling the fires. The blow-valve takes the water from the bottom of the boiler through an internal pipe secured with a tight joint to the shell of the boiler. The bottom blow-valve is generally made of the same size as the feed-valve, so that the boiler may be filled and emptied quickly.

The *surface blow-valve* is generally made about one-half as large as the feed-valve. It is used to remove the scum and other impurities floating near the surface of the water. The valve is connected with a system of perforated pipes extending through the boiler a short distance below the water-line, or with one or several perforated boxes or strainers in which the water, being undisturbed by ebullition, deposits the solid particles held in suspension.

The arrangement of the blow-valves and pipes of the boilers of the U. S. S. *Nipsic* is shown on Plate XXX. The bottom blow-valves of the several boilers on each side of the vessel are connected by means of composition branch-pipes, 2½ inches in internal diameter, with the main blow-pipe leading along the front of the boilers to the Kingston valve in the bottom of the vessel. The main blow-pipes are made of seamless drawn brass tubes, connected by flanges, and are provided with a slip-joint. The pipes of the surface blow-valves are connected with a stop-valve on the side of the vessel a short distance below the water-line; and a branch-pipe connects the surface blow-pipe also with the bottom blow-pipe.

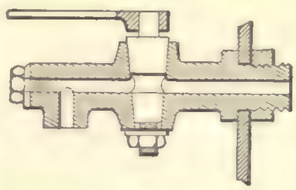
The blow-pipes are frequently exposed to violent shocks and jars when they are discharging the hot water into the sea. On this account bends must be avoided as much as possible and must be made with easy curves, and the pipes must be made of a tough material. The use of cast-iron is to be condemned. Brazed copper pipes are liable to split. Cast composition or seamless drawn brass pipes are nowadays generally used for the blow-pipes of United States naval boilers. (*See* "*Specifications for Boilers of United States Ironclad Miantonomoh and Class*," *section* 10, *chapter* vii.)

10. Instruments and Attachments for Measuring and Indicating the Height and the Density of the Water, and the Pressure and Temperature of the Steam.

Water-gauges.—The rules and regulations of the Supervising Inspectors of Steam-vessels provide that "all steamers having one or more boilers shall have three suitable gauge-cocks in each boiler; those having three or more boilers in battery shall have three in each outside boiler and two in each remaining boiler in the battery; and the middle gauge-cocks in all boilers shall not be less than 4 inches above the top of the flues, tubes, or crown of the fire-box."

United States naval boilers are fitted with three or four water-gauge cocks, placed from 4 to 6 inches apart, the lowest gauge-cock being placed on a line with the top of the back-connections. Either screw-valves with conical seats or plug-cocks are used for water-gauges. To keep their opening clear of any solid matter the valves are provided with feathers projecting beyond the opening of the valve-chamber (see Plate XXXIII.) Provision is made to clear plug-cocks by means of a wire, by forming a straight passage through them, which is ordinarily kept closed by a screw-plug at the front end (see figure 138). The gauge-cocks discharge the steam and water into a copper drip-pan provided with a drain-pipe which leads down into the bilge of the vessel or to a water-trap.

Fig. 138.



In addition to the gauge-cocks boilers are generally provided with water-gauge glasses, consisting of a glass tube from 12 to 18 inches long, the top and bottom of which communicate by means of suitable fittings with the steam and water spaces respectively, so that the water within the glass stands at the same level as the water within the boiler. Pipes lead from the top and bottom of the gauge well up into the steam-space and down into the water-space respectively, so that the indications of the water-level in the glass are not affected by violent ebullitions and foaming. These pipes should not be less than one inch in diameter, so as not to be clogged easily by pieces of loose scale or impurities in the water.

Gauge-glasses must be made of a white, transparent glass without bubbles or other defects which would impair their strength, and must be carefully annealed. Gauge-glasses have been introduced of late in which the side of the glass turned toward the boiler is covered with a white enamel, while the other half is left transparent; on the white background the line of the water-level is more plainly seen.

At the top and bottom the glass fits in a stuffing-box with a screw-gland, and is packed with soft rubber or cotton-wick. Cocks or screw-valves are provided for shutting off the communication between the gauge and the boiler at the top and bottom, and for opening a passage between the gauge-glass and the drain-pipe. All the passages of the gauge must be of such size and form that they are not clogged easily by dirt, and so arranged that they can be cleared while the boiler is in operation.

The water-gauge cocks and glasses are either placed directly on the front of the boiler or they are attached to a tube made of composition or cast-iron and having an internal diameter of 2½ or 3 inches. This tube is placed close to the boiler, with its upper and lower ends communicating with the steam and water spaces as described above.

Plate XXXIII. illustrates the type of water-gauge recently constructed for the boilers of the U. S. S. *Nipsic* and other United States naval vessels. A glass gauge and four gauge-cocks are attached to a composition casting, the general outline of which is cylindrical, so that its whole exterior can be finished by turning. This casting contains several small compartments and passages and one large chamber extending through the length of the casting and connected at the top and bottom with the boiler by means of composition pipes 1¼ inches in internal diameter. The communication between these pipes and the boiler may be shut off by means of plug-cocks placed on the shell of the boiler (see Plate XXX.) Four gauge-cocks, consisting of screw-valves with conical seats, and placed 6 inches apart, are screwed into a recessed plane face of the casting, and communicate directly with the large chamber. The cylindrical shell of the casting forms a shield enclosing the discharge-nozzles of the gauge-cocks and leading the steam and water blown out to a waste-passage at the bottom of the casting. A gauge-glass, having an external diameter of ¾ inch and an exposed length of 19 inches, enters at the top and bottom into small separate compartments, which communicate by means of screw-valves with the large chamber and with a waste-passage, to the lower end of which a copper drain-pipe ¾ inch in diameter is attached. Behind the gauge-glass a lamp is placed from the side, which can be moved up or down and clamped in any position.

These gauges are made right and left. All the fittings are of composition. The

handles of the gauge-cocks are all placed at the same angle when the cocks are shut.

Some years ago *percussion water-gauges* were frequently used on United States naval boilers in addition to the gauge cocks and glasses. They are especially intended to indicate the height of *solid water* when the boilers foam badly. They consist of a cylinder, made of composition metal, about 4 inches in diameter and about 20 inches long, connected at the top and bottom by means of pipes with the steam and water spaces of the boiler, and placed at about the same height on the front of the boiler as the water-gauge cocks and glass. This cylinder contains an easily-fitting piston, with a rod passing through a stuffing-box on the top, to which a handle is attached which leads downwards and carries a pointer at the same level as the piston. The latter having been raised clear of the water, it is easy to feel when it strikes the water on being pulled down suddenly, and the position of the pointer relatively to rings formed on the outside of the cylinder shows the height of the water in the boiler.

In another class of devices a *float* indicates the height of the water in the boiler. This float is formed frequently by a large hollow sphere which floats in an upright cylindrical vessel in which the water stands at the same level as in the boiler. The position of the water-level is indicated by a pointer, which is moved by a rod attached to the float.

In the *Belleville* boiler such a float is used to regulate the quantity of feed-water admitted by adjusting the opening of the feed-valve. In other cases the float admits steam to an alarm-whistle when the water falls below a certain height.

Floats are, however, seldom used on marine boilers; they are more applicable to stationary and steamboat boilers which are always fed with fresh water, and where their indications are not affected by violent motions of the vessel.

Fusible Plugs.—Another safeguard against the dangers arising from low water in the boiler is the fusible plug which closes a small hole in the water-heating surface of the boiler at a height below which the water cannot be allowed to fall without imminent danger. The plug is made of some metal or alloy which will melt before the iron is overheated to a dangerous degree. The discharge of steam through the hole thus formed gives warning of the danger and at the same time relieves the pressure within the boiler and retards the combustion.

The rules and regulations of the Supervising Inspectors of Steam-vessels require that all fire-box boilers shall have one plug of Banca tin 1 inch in diameter inserted in the crown of the back-connection. These fusible plugs are never used in United States naval boilers.

Salinometer-pots.—All boilers of United States naval vessels are provided with permanently-attached salinometer-pots for testing the density of the water in the boiler. The water-pipes through which the pots communicate with the boilers, as well as the drain-pipes, are made of copper or brass about $\frac{3}{8}$ inch in diameter, and are connected by means of screw-couplings, so as to be easily detached for cleaning. Stop-cocks are provided to open and shut off communication between the pipe and the pots and boilers. The water-pipe must be connected to the boiler at some place above the furnace-crowns where the temperature of the water is equal to that of the steam, and not in the vicinity of the feed-valve.

The object sought to be obtained in the construction of salinometer-pots is to maintain in an open vessel a constant flow of the water drawn from the boiler while testing its density, and to reduce this water to a fixed temperature below the boiling-point under atmospheric pressure, so as to avoid ebullition and the formation of clouds of vapor.

Long's salinometer-pot, which has been in use on United States naval boilers for many years, consists of two brass cylindrical vessels placed side by side and communicating at the bottom. The water enters one of these vessels, which is kept closed by a cover perforated with a few small holes for the escape of steam, through a central pipe closed at the top and perforated near its upper end. The rate of flow of the water from the boiler is regulated by a stop-cock. The water rises simultaneously in the two vessels. A central tube reaching nearly to the top of the second vessel, which is kept open, serves as an overflow. This overflow-pipe passes through the bottom of the pot and is coupled to a drain-pipe; another drain-pipe communicates with the bottom of the vessels to draw off the water from them. The hydrometer is placed in the open vessel, which is provided at the side with clamps for holding a thermometer which indicates the temperature of the water during the test.

Fithian's salinometer-pots have been used on several United States naval boilers since the introduction of higher steam-pressures. The hot water drawn from the boiler passes, before it enters the open vessel, through a coiled pipe immersed in a stream of cold water. By regulating the flow of the cooling water the temperature of the water which is to be tested can be regulated quickly and exactly.

Steam-gauges.—Each boiler must be connected with a separate steam-gauge, which must communicate directly with the boiler and not with the steam-pipe, so that the closing of a stop-valve does not put the gauge out of use. The gauge is located at a convenient place in the fire-room, and is connected with the top of the boiler by a copper or brass pipe about $\frac{1}{2}$ inch in diameter, to which a downward curve is given close to the

gauge, so that the water accumulating at this point prevents the hot steam from coming in contact with the spring of the gauge. Plug-cocks are placed on the boiler and on the gauge, and the pipe is connected to them by screw-couplings. It is advisable to use a soft lead washer as a packing in the coupling, as rubber is apt to swell and be squeezed out till it closes the opening of the small pipe.

United States naval vessels have generally, in addition to the spring-gauges attached to each boiler, one standard mercurial gauge, which is connected with the main steam-pipe of the boilers.

Thermometers.—All separate superheating-chambers should be fitted with thermometers, especially when the steam is superheated to a high degree. The thermometer must be immersed in the steam as far as possible, leaving only such a length of the stem exposed as is necessary to read the instrument. The part of the instrument which is immersed in the steam is surrounded by a perforated pipe; the projecting stem is protected by a shield-plate, or by a brass case fitted with a sliding-plate.

11. Safety-valves.—Each boiler must be provided with a safety-valve, arranged in such a manner that the communication between the valve and the boiler cannot be shut off. A safety-valve must also be provided for each separate superheating-chamber and feed-water heater. The safety-valve should be placed on the top of the boiler or be connected by an internal pipe with the highest part of the steam-space.

Safety-valves must be so arranged that they may be opened by hand in order to relieve the boiler of steam-pressure at any time and to try whether the valve moves freely in its seat. The rules of Government inspectors require that, in addition, each boiler shall carry a lock-up safety-valve of sufficient size, which, being set to blow off at the pressure allowed, is entirely beyond the control of the persons manipulating the machinery.

Safety-valves are weighted by applying the load to them either directly or by means of a lever. Springs are used almost universally instead of weights for directly-loaded valves on marine and locomotive boilers; they are also frequently used for lever safety-valves. Spring-loaded valves come more and more into use in sea-going steamers where steam of high pressure is used, on account of the difficulties incident to the use of heavy weights in consequence of the violent motions of vessels in rough weather. When the lever of safety-valves is loaded by dead weights it is placed in the fore-and-aft direction of the vessel.

In a spring-loaded valve the tension or compression of the spring increases with the lift of the valve, while the weight of a dead load is the same for every lift. But with a properly-proportioned, directly-loaded valve the increase of resistance of the compressed

or extended spring is trifling. When the spring acts on a lever some compensating arrangement should be adopted to counteract the effect of the increased resistance.

A safety-valve acting automatically must fulfil the following essential conditions—viz.:

It must be capable of discharging at a given pressure the greatest weight of steam which the boiler is capable of generating in a unit of time.

It must not allow the pressure within the boiler to rise above a fixed limit, and it must close quickly when the pressure falls below that at which the valve is set to open.

It must be reliable in its action under continued use; it must be simple in its construction and easily adjusted and managed.

The size of the valve must be proportioned to the greatest weight of steam which may be generated in a unit of time. Rules which determine the size of safety-valves by the dimensions of the grate or heating surface, or by the weight of coal consumed in a unit of time, are based on the supposition that under the given conditions a fixed rate of evaporation obtains, and apply consequently only to special classes of boilers. A *general* rule must determine the area of the valve by the *weight of steam* to be discharged in a unit of time and by the *pressure* at which it is to be discharged.

The weight of steam, in pounds, discharged into the atmosphere per second through an orifice having an area of 1 square inch, is approximately equal to the absolute pressure of steam in pounds per square inch divided by 70 when the steam-pressure is equal to or greater than 25 pounds per square inch above zero. (*Rankine*, '*Manual of the Steam-engine.*')

The *effective opening* of a safety-valve lifting automatically is very small relatively to the area of its disc, because the lift of the valve is always small. With the ordinary disc-valve a greater lift than $\frac{1}{10}$ inch should not be counted upon. This small lift is due to the rapid diminution of the force exerted by the steam-pressure on the valve as it rises from its seat. Various methods have been tried of increasing the lift of the valve by making the escaping steam impinge on a lip turned down around the rim of the valve, or by otherwise obstructing the passage of the escaping steam (see figure 3, Plate XXXIV., representing Ashcroft's safety-valve). But, in general, such arrangements tend also to produce an excess of pressure within the boiler over the pressure at which the valve begins to lift, or to make the action of the valve irregular or intermittent.

A further diminution of the effective opening of valves is due to the conical form ordinarily given to the seat.

The safety-valve must discharge the steam, when the evaporation is a maximum, so

rapidly that the greatest increase of pressure within the boiler does not exceed 10 or 12 per cent. of the pressure at which the valve begins to lift.

When the diameter has to exceed 5 inches in order to get sufficient area, it is better to increase the number than the size of the valves.

Thurston proposes the following formula for determining the area of safety-valves:

$$A = \frac{0.5\,w}{p + 10}$$

when $A =$ area of safety-valve in square inches;
$p =$ pressure of steam in pounds per square inch above the atmosphere;
$w =$ weight of water, in pounds, evaporated per hour as a maximum.

Rankine proposed the following rule for determining the area of safety-valves: *Multiply the number of pounds of water evaporated per hour by* 0.006; *the product will be the area of the valve in inches.*

The rules of the United States Supervising Inspectors of Steam-vessels, of the Board of Trade (English), and of Lloyd's Register require that the safety-valves of marine boilers shall have an area of not less than half a square inch to each square foot of grate-surface when the ordinary safety-valve is employed. But when a safety-valve of an approved pattern is used which gives a greater lift than the common safety-valve the size of the valve may be diminished.

In the report on safety-valve tests, made in 1875 at the United States Navy-Yard, Washington, D. C., by a special committee of the Board of Supervising Inspectors of Steam-vessels, it is stated that an ordinary disc-valve with a bevelled seat, having an area of *ten* square inches, will discharge *two thousand* pounds of steam in an hour at all pressures from 20 to 100 lbs. per square inch. The following rule for determining the size of safety-valves is deduced from these experiments:

Multiply the weight of water in pounds evaporated in one hour by 0.005; *the result is the area of the valve-disc in square inches.*

It is likewise recommended that the area of safety-valves should not exceed ten square inches, and that several valves be employed when a larger area is required for a boiler.

Numerous forms of safety-valves and arrangements for loading them have been devised. Annular valves and double poppet-valves have been used for the purpose of obtaining a large area of opening with a given lift. In other cases an auxiliary valve or piston has been used in combination with the safety-valve, with a view to increasing

the lift of the valve and ensuring its prompt seating when the pressure falls below the point for which the valve is set. But, generally speaking, the ordinary disc-valve is not only the simplest in construction, but most reliable in its action and least liable to derangement.

Disc-valves are made either with a conical or with a flat-faced seat. It is claimed for the latter that they are less liable to stick and that they present a larger opening with the same lift than the former. On the other hand, it is objected that it is more difficult to keep them tight, and that the steam escapes with greater difficulty through their opening, since it has to make two abrupt changes in direction. When a wide bearing-surface is given to flat-faced valves they are apt to have a trembling, vibratory motion when they are discharging steam.

Conical valves are most usually employed, the bevel of their seat forming an angle of 45°. With a narrow face the valve is more easily kept tight and the steam escapes with greater ease than with a wide face; some authorities claim that a width of $\frac{1}{16}$ inch is sufficient for the seat of a conical valve 4 inches in diameter. The valve and seat are generally made of composition metal for marine boilers, but in Ashcroft's valve (see figure 3, Plate XXXIV.) the bearing-surfaces are formed by nickel rings let into the valve and seat.

The valve is guided either by wings attached to the disc below its seat or by a central spindle working in a sleeve. The opinions of competent engineers differ as to which of these two devices for guiding the valve is preferable; both are liable to cause the valve to stick when they are fitted too close, in consequence of the lodgment of dirt or scale, or of unequal expansion when steam is raised quickly.

To prevent the canting of the valve in consequence of the oblique thrust thrown upon it by the lever as it lifts, the central spindle upon which the lever rests is often detached from the valve-disc; the latter is hollowed out on the top so that the point where the spindle rests upon the valve lies below the valve-seat. When this spindle is rigidly attached to the valve-disc it is connected with the lever by means of a short link. The pins or bolts of the articulated joints of the lever and link are often made of composition to lessen the liability of their becoming fast by rusting or by getting clogged with grease and dirt. To reduce the friction as much as possible it is best to make the lever turn on knife-edges, case-hardened.

The lever safety-valve recommended by the Board of Supervising Inspectors of Steam-vessels is represented in figure 2, Plate XXXIV. The following directions are given regarding its construction:

"All the points of bearing on lever must be in the same plane.

"The distance of the fulcrum must in no case be less than the diameter of the valve-opening.

"The length of the lever should not exceed the distance of the fulcrum multiplied by ten.

"The width of the bearings of the fulcrum must not be less than three-fourths (¾) of one inch.

"The length of the fulcrum-link should not be less than four (4) inches.

"The lever and fulcrum-link must be made of wrought-iron or steel, and the knife-edged fulcrum-points and bearings for the points must be made of steel and hardened.

"The valve, valve-seat, and bushings for the stem or spindle must be made of composition (gun-metal) when the valve is intended to be attached to a boiler using salt water; but when the valve is to be attached to a boiler using fresh water and generating steam of a high pressure, the parts named, with the exception of the bushings for the spindle, may be made of cast-iron.

"The valve must be guided by its spindle, both above and below the ground seat and above the lever, through supports either made of composition (gun-metal) or bushed with it.

"The spindle should fit loosely in the bearings or supports.

"When the valve is intended to be applied to the boilers of steamers navigating rough waters the fulcrum-link may be connected directly with the spindle of the valve, providing always that the knife-edged fulcrum-points are made of steel and hardened, and that the object sought by the link is obtained—viz., the vertical movement of the valve unobstructed by any lateral movement.

"In all cases the weight must be adjusted on the lever to the pressure of steam required in each case by a correct steam-gauge attached to the boiler. The weight must then be securely fastened in its position and the lever marked for the purpose of facilitating the replacing of the weight, should it be necessary to remove the same."

Figure 1, Plate XXXIV., represents the form of safety-valve used on the boilers of the U. S. S. *Nipsic* represented on Plates XII. and XXX.

Figure 3, Plate XXXIV., represents the Ashcroft spring safety-valve of the boilers of U. S. S. *Adams* and class. One valve of this description, 3 inches in diameter, was used on each boiler of this vessel. In addition there was one lever safety-valve of ordinary construction, having a diameter of 10 inches, which was connected with one of the main steam-drums and had an arrangement for lifting it from the fire-room. Each boiler had 24 square feet of grate-surface and 598.6 square feet of heating-surface, and was designed for a working pressure of 80 lbs. per square inch above the atmosphere.

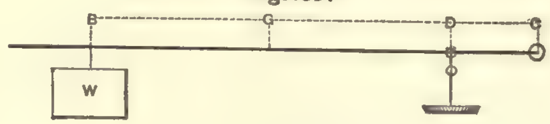
The Board of Trade (England) prescribes that, in case spring safety-valves are used in passenger-steamers, there must be fitted to each boiler at least two separate valves; the spring and valve must be so cased in that they cannot be tampered with; provision must be made to prevent the valve flying off in case of the spring breaking; screw lifting-gear must be provided to ease all valves, if necessary, when steam is up; the springs must be protected from the steam and impurities issuing from the valves; when the valves are loaded by direct springs the compressing-screw must abut against a metal stop or washer when the load sanctioned by the surveyor is on the valve; the size of the steel of which the spring is made is found by the following formula:

D = diameter or side of square of the wire, in inches;
d = diameter of the spring from centre to centre of wire, in inches;
S = load on the spring, in pounds.
k = constant = 8,000 for round and 11,000 for square steel.

$$D = \sqrt[3]{\frac{(S+d)}{k}}.$$

The accumulation of pressure is not to exceed 10 per cent. of the loaded pressure.

Fig. 139.



When p = pressure of steam in pounds per square inch above the atmosphere,
A = area of valve in square inches,
W = weight of the load applied to the lever, in pounds,
w = weight of the lever and its attachments, in pounds,
GC = distance of centre of gravity of lever from fulcrum C,
w_1 = weight of valve and spindle, in pounds,
DC = distance of axis of valve from fulcrum C,
BC = distance of centre of gravity of load from fulcrum C,

the steam-pressure at which a safety-valve loaded by means of a lever (see figure 139) will open is found by the formula:

$$p = \left(\frac{W \times \overline{BC} + w \times \overline{GC}}{DC} + w_1\right) \div A. \quad [I.]$$

The weight of the load required with a lever of a given length for a given steam-pressure is found by the formula:

$$W = \frac{(p \times A - w_1)\,\overline{DC} - w\,\overline{GC}}{\overline{BC}}. \quad [\text{II.}]$$

The length of lever required with a given weight of the load and a given steam-pressure is found by the formula:

$$\overline{BC} = \frac{(p \times A - w_1)\,\overline{DC} - w\,\overline{GC}}{W} \quad [\text{III.}]$$

The results given by the foregoing formulæ are modified in practice by the friction of the articulations and of the stem, and the position of the weight on the lever must be finally adjusted when steam is on the boiler, so that the valve lifts at the required pressure.

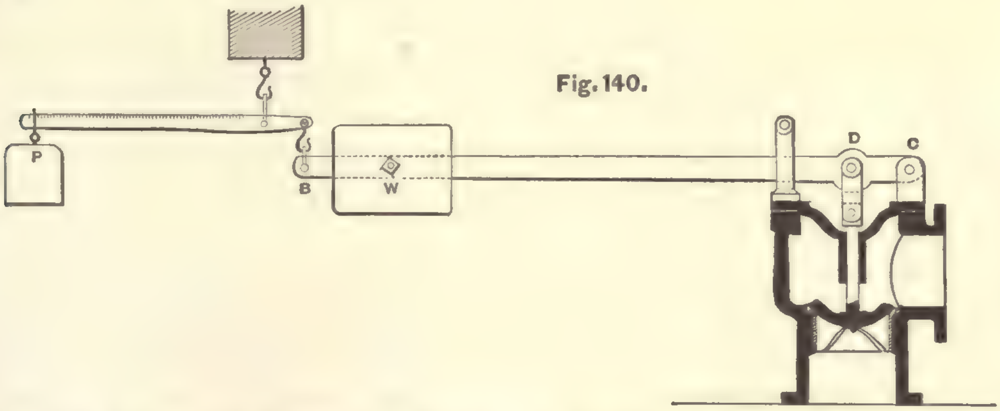


Fig. 140.

Figure 140 represents a practical method of weighting a safety-valve lever, taking into account the load due to the weight of lever and valve and to friction, when it is not convenient to adjust the valve under steam—viz., calculate the total effective pressure, $p \times A$, acting on the valve; apply at the end of the lever B an ordinary weigh-beam, which tends to raise the lever-arm; adjust the load P on the weigh-beam so that it will balance a weight equal to $\frac{p \times A \times DC}{BC}$; then adjust the weight W on the valve-lever till it brings the lever and the weigh-beam into a horizontal position.

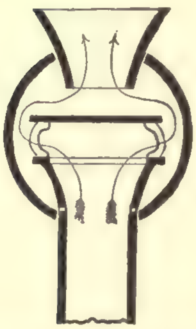
12. Miscellaneous Attachments of Boilers.

Escape-pipes.—The steam discharged by the safety-valves and by the exhaust of the steam-pumps and other auxiliary engines is conducted to the escape-pipe and from it discharged into the atmosphere. There are one or several escape-pipes, which are carried up alongside the smoke-pipe to a greater or less height above the upper deck.

With a hoisting chimney the escape-pipe reaches either only to the top of the stationary section of the chimney, or it is made telescopic, having a movable section attached to the movable section of the chimney, which slides within the lower stationary section, the latter being provided with a stuffing-box at its upper end.

The escape-pipe is generally made of copper. Its upper end is either simply made flaring or it is provided with an arrangement for intercepting the water which is carried up with the steam (see figure 141).

Fig. 141.



The U. S. S. *Nipsic* has a single escape-pipe, 9 inches in diameter, which is carried up at the forward side of the chimney to the top of the stationary section. The safety-valve chambers of the boilers on each side of the vessel are connected with each other by pipes 5½ inches in diameter, and communicate with the escape-pipe by means of a branch-pipe 7 inches in diameter. These pipes are made of copper, No. 14 B. W. G. thick, and are connected by composition flanges.

The exhaust-pipes of auxiliary engines should be connected directly with the escape-pipe, and not with any of the safety-valve chambers, as is often done in order to effect a saving in the length of the pipes, because the steam and condensed water leaking through the safety-valve will keep the boiler damp when it is not in use.

Justice's quieting-chamber is designed to prevent the deafening noise produced by steam issuing from safety-valves, from the exhaust of high-pressure engines, etc. The chamber, which is either cylindrical or of any other convenient shape, is filled with balls of suitable material and of proper size, confined compactly between copper gratings; for low pressures balls or beads of annealed glass are found best, while for high pressures hollow copper or brass balls of small size are used. The current of steam flowing through this chamber is broken up into numerous streamlets in its passage through the tortuous interstices formed by the balls. The vibrations produced in the several balls by the impact and friction of the steam are not uniform and interfere with one another, and thus do not produce sound. By making the total area of the openings sufficiently large the steam is allowed to escape without an appreciable increase of back-pressure. The area of the exit-opening is always in excess of that of the inlet-pipe. The cross-area of the chamber is proportioned to the pressure and volume of the steam; the diameter of the chamber is from five to six times the diameter of the escape-pipe. The depth of the chamber is about 8 inches for all sizes.

Figure 142 shows a sectional elevation of a quieting-chamber, which communicates below with a safety-valve and above with the escape-pipe. The safety-valve, which is

placed on the main steam-pipe between the boilers and a stop-valve, can be opened by means of a hand-lever, and discharges the steam through the quieting-chamber into the escape-pipe.

Figure 143 is a sectional elevation of another form given to the quieting-chamber. The latter has a central pipe passing through it, which is provided with a valve, so that the steam may be discharged either through the chamber or directly into the escape-pipe. The valve may be loaded to discharge the steam automatically, or it may be lifted by a hand-lever.

Similar quieting-chambers are introduced between the blast-pipes and nozzles of locomotives, steam-launches, torpedo-boats, etc.

Fig. 142.

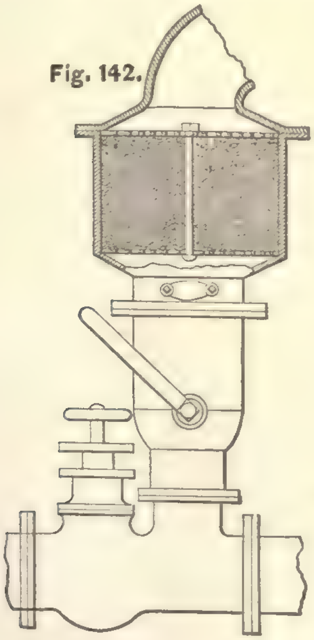
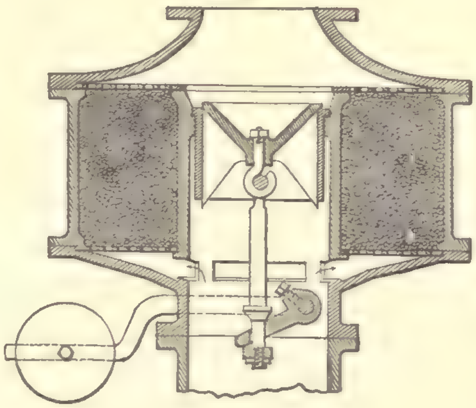


Fig. 143.



In *Shaw's noise-quieting nozzle* the steam escapes through cylindrical coils of wire, the diameter and length of the coils being such that, when compressed nearly to contact, the spaces between the turns of the coils will make a total area of opening much greater than that of the steam escape-pipe. As the individual turns of the wire coils cannot vibrate without coming in contact with the adjacent ones, interference and consequent silence results in the same way as two vibrating piano-wires, if brought together, will immediately destroy each other's sound. The spirals are opened wider by any increase of steam passing through, and this action, as well as the tremulous motion of the spirals produced by the issuing steam, prevents their clogging by an accumulation of foreign

matter. The spiral coils are made of brass wire about $\frac{1}{8}$ inch thick, and are from 4 to 5 inches long. A greater or less number of coils are arranged in various ways for each escape-pipe.

Fig. 144.

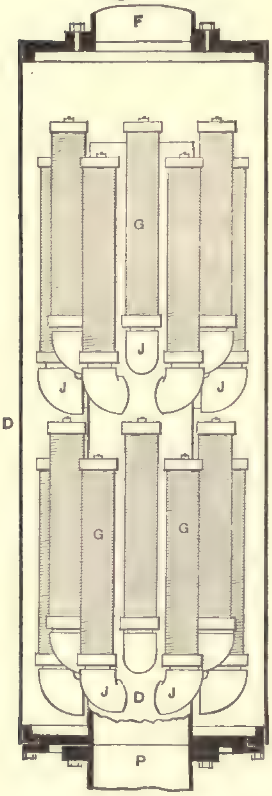


Figure 144 represents Shaw's noise-quieting nozzles arranged in clusters for large steamships. P is the escape-pipe from safety-valve, on which the casing D, containing the cluster of nozzles, is bolted. G are nozzles of spiral wire, having a solid top, and secured to elbows, J, that are connected with the escape-pipe P. The steam escapes through the wire coils into the casing D, whence it is led to the escape pipe F.

Figure 145 represents a sectional elevation and top view of another arrangement of the noise-quieting nozzle. The nozzle is made entirely of brass and copper. The bottom flange connects with the escape-pipe close to the safety-valve. The steam escaping from the safety-valve is conducted into the base B and into a central tube, C, where it is distributed to numerous coils of brass wire, F, secured in the top plate of base B and in the central tube C. Escaping between the turns of these coils, the steam enters the copper casing P, from which it is conducted through the regular escape-pipe to the outer air. A valve, G, is sometimes provided at the top of the central pipe C, said valve being loaded with about 2 lbs. pressure, which guarantees a sufficient outlet without reference to the coils F; but this valve is not a necessity, as abundant area of outlet exists in the brass coils F.

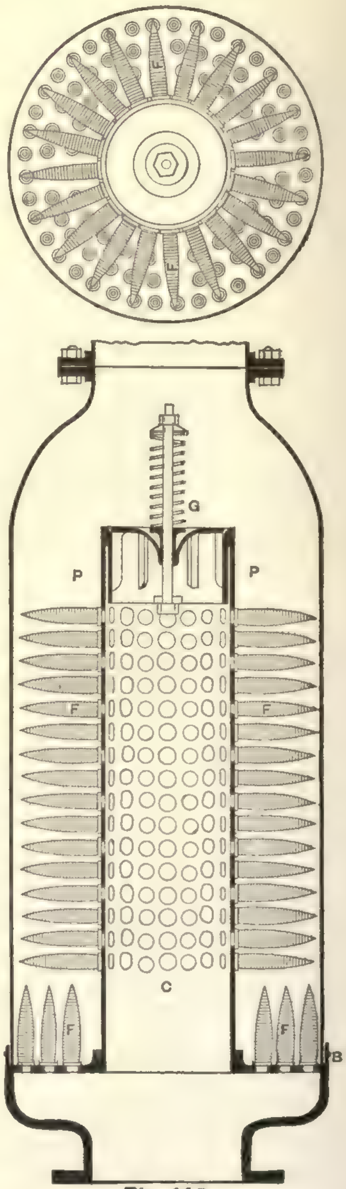


Fig. 145.

Bleeding valves and pipes are intended to pass waste steam into the condenser in-

stead of blowing it off through the safety-valve. For this purpose a copper pipe, having a diameter of about 4 inches, leads from the main steam-pipe to a stop-valve on the top of the condenser, another stop-valve being placed between the main steam-pipe and the bleeding-pipe.

The *reverse* or *vacuum valve* is a small safety-valve opening inwards, designed to open and thus prevent the collapse of a boiler in case the pressure within the boiler falls below the atmospheric pressure. These vacuum-valves were generally attached to boilers as long as steam of very low pressure was used and the shell of boilers was proportionately weak, but they are seldom used nowadays.

Stop-valves and steam-pipes are attached directly to the boilers to supply the steam-pumps and other auxiliary engines, the distiller, steam-whistle, and steam-blast with steam when communication between the main steam-pipe and the boilers is shut off.

Drain-cocks are fitted to the bottom of the boilers, to superheating-chambers and steam-drums, and to all valve-chambers and pipes where water is liable to lodge after the boilers are emptied.

In the U. S. S. *Nipsic* the drain-pipes discharge the waste water into a cylindrical wrought-iron tank placed in the spandrel under the after boiler. The several drain-pipes communicate with a common pipe, which is connected to a stop-valve placed on the top of the tank. Another pipe, which is likewise provided with a stop-valve, takes the water from the bottom of the tank to the feed-pumps. A gauge-glass shows the height of the water in the tank.

13. Covering for Boilers.—The saving in fuel which may be effected by preventing the loss of heat by radiation and convection from the shell of boilers, steam-pipes, etc., has been discussed in section 6, chapter iii. Besides the economic advantage resulting from surrounding boilers with non-conducting materials, the reduction of the temperature in the confined spaces around the engines and boilers of a vessel is of great importance. It is also necessary, especially in single-deck vessels, to provide a tight covering for the top of boilers to protect them from the water which may leak through the deck.

The principal methods used for protecting the shells of marine boilers are the following: the boilers are surrounded with an air-tight casing enclosing an air-space; or they are covered with hair-felt or other loose, fibrous material, held in place by an outer casing; or they receive a thick coating of some cement applied like plaster to their surfaces. Sometimes several of these methods are used in combination. These different methods of covering can be made equally effective, as far as the prevention of loss of heat from the covered surface is concerned, provided the casing is fitted with sufficient exactness

and the covering or coating is applied in sufficient thickness. Their relative value is, therefore, to be measured by the weight, the first cost and the durability of the covering, and by the facility with which it can be removed and replaced for the purpose of examining and repairing the covered parts.

The entire cylindrical shell and the back of the boilers of the U. S. S. *Miantonomoh* and class are covered with an air-tight casing of galvanized iron, enclosing an air-space of $1\frac{1}{2}$ inches between the boiler and the casing. (*See Specifications of Boilers of U. S. S. Miantonomoh and class, section* 10, *chapter* vii.)

Cow-hair felt, stitched on canvas, weighing 1 pound per square foot when $1\frac{1}{2}$ inches thick, has usually been employed for covering the boilers of United States naval vessels. The specifications for the cylindrical boilers of the U. S. S. *Adams* and class prescribe that "after the boilers are in the vessel, have been tried with steam, and all leaks have been made tight, the boilers are to be covered with felting $1\frac{1}{2}$ inches thick, strongly stitched to No. 1 canvas, and secured by four hoops, 2 inches wide, encircling the boiler; and over this is to be placed sheet-lead of No. 14 wire-gauge, securely soldered at all edges."

Rectangular boilers are covered in this manner on the top, and on the back and sides for some distance down; the temperature of the water in the lower part of the boiler is generally so much less than the temperature of the steam that it is not necessary to extend the covering to the bottom of the boiler. On the felting is frequently placed a covering made of wooden staves, tongued and grooved. The manner of securing the wood casing to launch-boilers is shown on Plate XVI. On steam-pipes these staves are generally held together by brass hoops drawn together by a single bolt.

When steam of more than 45 pounds pressure is used its temperature is sufficient to char the felt when it comes in immediate contact with the metal of the boiler. On this account various contrivances have been designed for maintaining a narrow air-space between the felt and the boiler, and asbestos boards or other mineral substances of low thermal conductivity are sometimes placed between the boiler and the felt.

Various mastic compositions of clayey material, and cements containing an admixture of asbestos in greater or less proportions, are applied like plaster either directly to the surface of the boiler-shell or to a wire netting stretched over the latter. The weight of such a covering is considerable. The most serious objection to its use on steam-chambers is the difficulty of removing and replacing it for the purpose of examining the covered parts.

"*Mineral wool*" is a loosely-cohering, fibrous substance resembling coarse wool, formed by blowing a jet of steam into a stream of fluid slag. It is used as a non-con-

ductor by packing it in a space formed around the protected vessel by an outer casing. It sometimes contains foreign substances which attack the iron under the influence of heat and moisture.

14. Feed-water Heaters and Filters.—*Feed-water heaters* are designed to utilize waste heat and to lessen the difference of the temperatures of the steam and water in the boiler. The latter is an important consideration; the introduction of a mass of cold water in a highly-heated boiler causes injurious local contractions, and the difference of the temperatures in the top and bottom of cylindrical boilers, amounting often to from 100° to 200° Fahr., produces often far greater strains than those due to the steam-pressure.

The saving of heat effected by the use of heaters, in per centum of the total heat expended, may be expressed by the formula:

$$\varepsilon = \frac{t_1 - t}{T - t},$$

where t, t_1, and T are the temperatures of the feed-water before and after it passes through the heater, and the total heat of an equal weight of steam, respectively. This saving may be in many cases to a great extent counterbalanced by the cost and weight of, and the space occupied by, the heater, and by the additional cost and labor required to keep it in order.

When the temperature of the escaping gases in the boiler-uptake exceeds the limit given in section 11, chapter ii., the economic and potential evaporative efficiency of the boiler will be increased by utilizing the excess of heat in raising the temperature of the feed-water. With a well-designed boiler this should not be necessary, and the arrangement of the heater-pipes in the uptake of a marine boiler presents many difficulties and inconveniences.

When the engines are fitted with a jet-condenser, and the boilers are fed with salt water, heaters are used to advantage to impart to the feed-water a portion of the heat contained in the supersalted water which is blown off to reduce the saturation of the boiler. In the U. S. S. *Wabash* each boiler, containing 83.5 square feet of grate-surface, was provided with a heater lying beneath the floor-plates of the fire-room. This heater was composed of a cast-iron cylindrical shell, 12¼ inches in external diameter, containing 31 brass tubes 1¼ inches in external diameter and 13 feet long. The supersalted water of the boiler was blown off continuously from the surface by a cock and pipe, and passed around the tubes on its way to the sea, while the continuous feed passed through these tubes on its way from the hot-well to the boiler. When the

water of the boiler was kept at a density of 1¾ thirty-seconds the feed-water received an accession of temperature of about 30° Fahr.

With non-condensing engines the exhaust steam may be used to heat the feed-water. The steam is either blown into an open tank, where it mingles with and is condensed by a shower of water, or the heater is constructed on the principle of a surface-condenser—the steam being condensed as it passes through a nest of tubes around which the feed-water circulates.

The *Berryman heater* consists of a closed cylindrical wrought-iron tank, the bottom of which is bolted to a casting divided by a partition into two compartments. The interior of the tank is occupied by a number of siphon-shaped brass tubes, which are secured with both ends in the bottom plate of the tank in such a manner that their ends communicate with either compartment of the lower casting. The exhaust steam enters one of these compartments, and, after parting with its heat in passing through the tubes, it is discharged from the other compartment. The feed-water is forced by the pump into the tank near the bottom, and passes out through an opening at the top. With this arrangement the warmest water rises naturally to the top and passes off to the boiler, and foreign matter held in suspension in the feed-water has a chance to settle in the bottom of the tank.

Filters.—United States naval boilers using high pressures of steam have been fitted with *feed-water filters* consisting of a tank divided by screens into several compartments, which are filled with various substances for filtering the water or neutralizing the fatty acids contained in it.

In *Selden's filter*, as fitted to the U. S. S. *Miantonomoh*, the water coming from the hot-well enters at the top of a tank, and passes through a vertical partition formed by a sheet of Burlap cloth placed between two wire screens into an upper compartment which is filled with coke. The plate forming the bottom of this compartment is perforated at one end with 62 ¾-inch holes, through which the water passes into the lower compartment, which is filled with sponge. The bottom plate of this compartment has an equal number of holes near the opposite side of the tank, through which the water flows into the channel-way, whence it is withdrawn by the feed-pump. Doors are provided for removing the screens, the coke, and the sponge for the purpose of cleaning or renewing them.

15. Feed-pumps and Injectors.—When the boilers are fed with fresh water the weight of water evaporated as a maximum is the least quantity which the feed-pump must be capable of delivering in a given time; when sea-water is used the weight of water to be blown off to maintain the water in the boiler at the proper density has to be

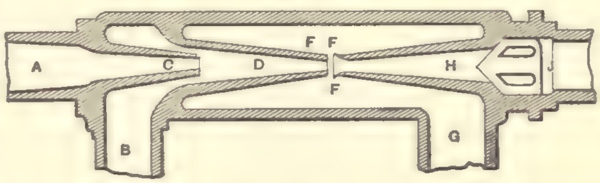
added to the weight of water evaporated in a given time. The feed-pump should, however, be capable of discharging about twice the quantity of water evaporated and blown off in a unit of time, in order to supply losses due to priming and leakage and to make allowances for irregularities in the working of the pump.

In calculating the dimensions of a pump it may be assumed that the volume of the water discharged is ordinarily about 75 per cent. of the space displaced by the plunger per stroke of pump.

According to the foregoing rule the capacity of the main feed-pump connected with the engines is to be calculated, as well as the least capacity of the auxiliary steam-pump. But it is advantageous to increase the dimensions of the latter pump so that it may be worked at a low speed; because with a slow-working pump shocks in the feed-pipes are avoided, and the hammering action of the check-valves is lessened, and the volume of water discharged relatively to the space-displacement of the piston is increased.

The *feed-water injector* was invented by Giffard, a French engineer, in the year 1858. In its simplest form (see figure 146) the injector consists of a pipe, A, for the admission of steam, which, escaping through the conical nozzle of the *receiving-tube* C at a high velocity, is joined by water which, flowing in through the pipe B, mingles with and condenses the steam in the conical *combining-tube* D. The condensed steam gives an impulse to this water, which is driven in a continuous stream through the *delivery-tube* H and the check-valve J into the boiler, provided it possesses sufficient velocity. During the passage of the water from D to H it is driven across the space F, called the *overflow*, which communicates by means of the *overflow-nozzle* G with the outside air. If too much water is supplied to the steam some water may escape at this point and flow out through the overflow-nozzle; if there be too little water air will be drawn in at G and carried into the boiler with the water.

Fig. 146.



The fact that a mass of steam should be capable of imparting to a much larger mass of water sufficient velocity to overcome even a higher pressure than that which caused the original motion of the relatively small mass of steam, has frequently been looked upon as a paradox. This action of the injector depends on the following principles:

The change in the molecular condition of the steam by condensation does not affect the motion of its particles. The mass of condensed steam, moving with its original high

velocity, produces a concentrated effect by its impact on the mass of the condensing water; and the resultant momentum of the two unelastic fluids is equal to the sum of the momenta of their masses before the impact. (*See equation* [II.])

An injector made as shown in figure 146 is known as a *fixed-nozzle injector*. With a given steam-pressure it will give a constant feed of a given quantity. To adapt the instrument to variations in the steam-pressure, and to effect variations in the quantity of feed-water delivered, the areas of the openings of the conical nozzles have to be altered in order to diminish or increase the steam or water supply. This adjustment was an essential feature of Giffard's injector. It is usually effected by means of a tapering spindle which can be raised or lowered by means of a screw within the receiving-tube, and by making either the receiving-tube or the combining-tube movable, so that by raising or lowering the same the annular space between the receiving-nozzle and the combining-tube is either enlarged or contracted. In the *fixed-nozzle injectors* the admission of steam and water is regulated by stop-valves in the supply-pipes; but the range of these instruments, as far as steam-pressure, temperature, and quantity of feed-water are concerned, is much more limited than that of the *adjustable injectors*.

The first action of the steam-jet issuing from C (see figure 146) is to drive the air out of the tube D, thus forming a more or less perfect vacuum in the chamber surrounding the nozzle C, in consequence of which the water will be lifted to a greater or less height in the supply-pipe. This lifting power of the injector may be greatly improved by giving to the openings suitable forms and dimensions. The water is frequently lifted from 6 to 8 feet; and it is claimed that with some large injectors of improved form a lift of 18 feet has been obtained. The water to be lifted must be free from air, and its initial temperature must be less than the boiling-point of water under the diminished pressure existing in the chamber surrounding C. Therefore, when a feed-water heater is to be used in connection with an injector, it is better to place it between the latter and the boiler.

The quantities of steam and water admitted must be so regulated that the jet of steam is completely condensed; otherwise a certain quantity of vapor will enter the chamber F and escape into the atmosphere, proving a complete loss. The temperature of the water-jet issuing from D must be less than 212° Fahr., otherwise the water will vaporize as it is brought into communication with the atmosphere in passing from D to H. The steam must be perfectly *dry* to give the best results.

The relation existing between the quantities of water and steam admitted, and their respective temperatures, is expressed by the following equation:

Calling t = final temperature of the feed-water discharged at H,

ϑ = initial temperature of the feed-water entering at B,

T = total heat contained in a pound of steam,

Q = weight of steam in pounds expended in a unit of time,

q = weight of water entering at B in a unit of time,

we have
$$(Q + q)\,t = Q\,T + q\,\vartheta;$$
hence
$$Q(T - t) = q\,(t - \vartheta);$$
$$\frac{q}{Q} = \frac{T - t}{t - \vartheta}. \quad \text{[I.]}$$

As the quantity T varies little with the pressure of the steam, the value of the proportion $\frac{q}{Q}$ depends principally upon t and ϑ—that is, the final and initial temperatures of the feed-water.

Neglecting the effect of friction and other disturbing influences occurring in practice, the relation existing between the velocities of the steam-jet and water-jet is expressed by the following equation, in which

v = the velocity of the mass of steam Q issuing from the receiving-tube;

u = the initial velocity of the mass of water q entering at B;

w = the velocity of the water-jet issuing from the combining-tube:

$$w\,(Q + q) = Q\,v + q\,u;$$
$$w = \frac{Q\,v + q\,u}{Q + q}. \quad \text{[II.]}$$

Calling F = the cross-area of the nozzle of the receiving-tube,

F_1 = the cross-area of the larger orifice of the combining-tube,

G = the cross-area of the nozzle of the combining-tube,

G_1 = the cross-area of the feed-pipe,

w_1 = the velocity of the water passing through G_1,

m = the specific volume of the steam,

we can represent the mass of water delivered in a unit of time by the following expressions:

$$Q + q = G\,w = G_1\,w_1 = \frac{F\,v}{m} + F_1\,u. \quad \text{[III.]}$$

The water-jet entering the boiler must perform the same amount of work as an equal mass of water issuing from the boiler under the pressures existing within the boiler

and the injector would be capable of doing. This is expressed by the following equation:

$$(Q + q)(h - x - h_2) = (Q + q)\left(\frac{w^2 - w_1^2}{2g}\right), \quad [\text{IV.}]$$

where h = the height of a column of water representing the absolute steam-pressure in the boiler;

h_2 = the height of the nozzle of the receiving-tube above the water-level within the boiler;

x = the height of a column of water representing the absolute pressure of the water at the mouth of the combining-tube.

Calling k = the height of a column of water representing the atmospheric pressure,

h_1 = the height to which the water is lifted,

we have

$$k - h_1 - x = \frac{u^2}{2g}. \quad [\text{V.}]$$

(*See Weisbach, 'Lehrbuch der Ingenieur und Maschinen-Mechanik,' dritter Theil II. Abtheilung.*)

By means of the foregoing equations the duty of an injector under given conditions, and the cross-area of the openings of the various parts of an injector for a given duty, may be calculated.

The causes decreasing the efficiency of injectors are friction, the shocks experienced by the water in the passages, the incomplete condensation of the steam and the admixture of air with the water-jet, and the waste of water at the overflow.

The least quantity of water which can be delivered by an injector is generally not less than 60 per cent. of the largest quantity delivered under the same conditions of temperature and pressure.

Experiments made in the year 1879 on Irwin's injector (see *Franklin Institute Journal*, February, 1880) indicate that on the whole the ratio of the weight of water delivered to the weight of steam used (or $\frac{q}{Q}$ of equation [I.]) decreased as the pressure of steam increased from 15 to 105 pounds per sq. inch above the atmosphere; that, on the contrary, the work done, expressed in foot-pounds per pound of steam, increased under the same conditions, the water being delivered in every case against a pressure equal to that of the steam used; that the ratio $\frac{q}{Q}$ decreased likewise when the delivery of water was less than the maximum for the pressures and temperatures of steam and water. The largest amount of work was done when the steam and water pressures were 90

pounds per square inch above the atmosphere, and the injector delivered 15.71 lbs. of water, supplied under a head of 6½ inches, per pound of steam; the work done in this case being equal to 3449.94 foot-pounds per pound of steam used. Assuming that a pump uses from ¾ to 1½ lbs. of steam for every 33,000 lbs. of water lifted one foot high, the highest efficiency of the injector in the above experiments was nearly from 13 to 6.5 times less than the efficiency of a steam-pump. Since, however, in the injector nearly all the heat of the steam which is not converted into mechanical work is utilized in raising the temperature of the feed-water, the injector compares favorably with a steam-pump as a feed apparatus.

There are certain inconveniences connected with the use of injectors which have prevented its general adoption as a feed apparatus for marine boilers—viz., the rolling of the ship is apt to cause a break in the water-jet; the foaming of the boilers interferes with its action; it is easily disarranged by particles of salt or other solid matter entrained by the steam or the feed-water; any air entering through the overflow spoils the vacuum of the condenser. Besides, all steam-vessels must carry steam-pumps for various purposes, so that the addition of injectors is unnecessary.

The difficulty of making by hand the proper adjustments regulating the admission of steam and water, which become necessary whenever the steam-pressure changes, led to the introduction of the *self-adjusting* injector, manufactured by William Sellers & Co., Philadelphia (see figure 2, Plate XXXV.) The upper end of the *combining-tube* C is made in the form of a piston, which slides freely in the exterior case; the lower part of the combining-tube is guided by a sleeve on the upper end of the *delivery-tube* D. The overflow-valve is closed as soon as the apparatus begins to work; if now the water-supply becomes too great a portion of the water escapes by the opening O in the upper part of the delivery-tube, and, accumulating in the chamber surrounding the combining-tube, presses under the piston and raises the combining-tube; on the other hand, when the feed-supply is insufficient a partial vacuum is formed under the piston, and the combining-tube is forced down till the increased feed-supply establishes equilibrium on both sides of the piston. In this manner the instrument regulates automatically the water-supply so as to give always the best result with the pressure and weight of steam used, and the indraught of air and waste of water at the overflow is avoided.

The conical spindle which regulates the flow of steam in the receiving-tube is perforated by a narrow passage bored along its axis, which communicates with the steam-space through grooves at the screwed end, when the valve W, formed by an enlargement of the spindle, is raised. The valve W seats on the upper side of a second valve, X, which in turn seats on the receiving-tube A. The small jet of steam which escapes

through the passage in the spindle before the valve X is raised is more effective in exhausting the air and lifting the water in the supply-pipe than a jet escaping through the narrow annular space between the taper plug and the receiving-nozzle.

With this central jet water is raised from 10 to 18 feet in the supply-pipe, according to the size of the instrument.

To start the instrument the lever K is drawn back a short distance till the collar on the spindle comes in contact with the lower side of the valve X. As soon as water appears at the overflow the lever is drawn entirely back and the valve X lifted from its seat, admitting a free flow of steam through the receiving-tube. Then, after closing the overflow-valve by rod L and lowering latch V into teeth of ratchet, the lever K may be pushed in to any required point between the stops on the rod L so as to obtain the desired water-supply.

This instrument has a greater range than the ordinary adjustable injector: the minimum water-supply is 40 per cent. of the maximum supply, a larger quantity of water is discharged by instruments of the same size, and the self-adjusting injector is capable of working with hotter water. Experiments made by the manufacturers with this instrument gave the following results:

Pressure of steam in pounds per square inch.....	20	40	60	80	100	120	140	150
Admissible temperature of feed-water before entering injector, in degrees Fahr..................	138	135	130	130	132	133	127	128

The self-adjusting injector works to the best advantage when it is lifting water, and in no case must the water be fed to it under pressure.

The numerical size of an injector is the diameter of the smallest part of the delivery-tube expressed in millimetres.

Numerous modifications have been made in the form of injectors by different makers with a view to simplifying their construction and manipulation and extending the range of their action.

Figure 3, Plate XXXV., represents *Koerting's universal lifting-injector*, which consists of two injectors combined in the same chamber in such a manner that the delivery-tube of the first injector communicates by means of lateral passages with the combining-tube of the second injector. The two steam-valves V, V′, and the overflow-cock E, are connected with the lever A in such a manner that the same movement of this lever sets the apparatus in operation. By moving the lever in the direction of the

arrow the valve V is first raised slightly from its seat, and as the steam rushes out through the open overflow-cock E the water is lifted and enters J. By the continued movement of the lever the valve V is opened wide, and as soon as the first injector is in operation its communication with the overflow by means of E is closed, and the water is forced into the combining-tube of the second injector. At this moment the steam-valve V′ of the second injector begins to lift, and when the second injector is in full operation its communication with the overflow by means of E is likewise closed, and the water is forced through the check-valve into the boiler. These several operations take place in such rapid succession that, practically, it is sufficient to raise the lever to start the apparatus.

It is claimed that with this injector water having an initial temperature of 156° Fahr. can be lifted, and that the temperature of the water is raised to 190° Fahr. in the combining-tube of the first injector, the pressure produced in the passages between the first and second injectors being considerable, so that the boiling-point of the water is raised and the condensation of a greater quantity of steam is made possible.

CHAPTER XVI.

TESTS, INSPECTIONS, AND TRIALS OF STEAM BOILERS.

1. Testing Boilers.—All new boilers and all boilers that have been extensively repaired must be subjected to a hydraulic pressure in excess of the highest working pressure, in order to test the tightness of the seams and rivets, the soundness of the plates, and the structural strength of the boilers. Such tests must be repeated periodically during the lifetime of the boiler.

A test-pressure equal to three times the working pressure was formerly held necessary by many authorities, but nowadays it is not considered prudent to subject marine boilers of the ordinary form to so severe a test. An excessive pressure may produce injuries which do not become apparent during the short test, but which continue to increase under the ordinary working pressure when the boiler is put into regular use. The test-pressure must in no case strain any part of the boiler beyond the limit of elasticity of the metal.

Section 4418 of the 'Revised Statutes of the United States' provides that "all boilers used on steam-vessels, and constructed of iron and steel plates, inspected under the provisions of section 4430 (see section 2, chapter v.), shall be subjected to a hydrostatic test in the ratio of 150 lbs. to the square inch to 100 lbs. to the square inch of the working steam-power [pressure] allowed."

United States naval boilers, when new or extensively repaired, are also subjected to a test-pressure equal to one and a half times the highest working pressure above the atmospheric pressure.

French laws require that tubular boilers of merchant-vessels are to be tested to double the working pressure above the atmosphere at least once a year and whenever repairs or alterations have been made on them. The boilers of French naval vessels are subjected, when new, to a test-pressure equal to twice the working pressure, and annually thereafter to a test of one and a half times the actual working pressure above the atmosphere; but this pressure is to be kept on the boilers not longer than five minutes. (*Ledieu*, '*Traité des Appareils à Vapeur de Navigation*,' vol. ii.)

The 'Steam Manual,' issued by the English Admiralty (1879), contains the following instructions regarding "Periodical testing by water-pressure of the boilers of Her Majesty's ships and vessels in commission":

"In the case of ships having new boilers, or boilers repaired for a commission of four years, the boilers are to be tested by water-pressure at the end of two years' service, and subsequently at half-yearly intervals during the remainder of the commission.

"As regards ships whose boilers have been repaired for shorter periods of service the boilers are to be tested by water-pressure at the end of six months' service, and subsequently at half-yearly intervals.

"During the application of water-pressure the boilers are to be carefully examined, and proper gauges are to be used to detect any change in the form of the furnaces, combustion-chambers, etc.

"The water-pressure is to be double the working pressure, provided that during the examination no indications of weakness are observed. Should, however, any indications of probable permanent deformation be observed the test is to cease, and the working pressure is then to be limited to one-third that of the test-pressure arrived at before such indications were seen.

"The water-pressure is intended to supplement, not to supersede, the occasional drill-testing. Should the latter test reveal unusual thinness of any plates the water-pressure is to be very carefully applied, in order that injury may not be caused by overpressure."

The Board of Trade (English) regulations for marine boilers provide as follows: "All new boilers, and boilers that have been taken out of ships for thorough repair, must be tested by hydraulic pressure up to at least double the working pressure that will be allowed, previous to the boilers being replaced in position, to test the workmanship, etc.; but the working pressure is to be determined by the stay-power, thickness of plates, and strength of riveting, etc."

Anderson states that the boilers belonging to the British War Department are subjected periodically, after about every 500 hours of actual work, to a hydraulic pressure equal to double the pressure to which the safety-valve is ordinarily loaded, or to one-third of their ultimate strength.

The usual method of testing boilers is to fill them with water and produce a pressure within them by means of a hand force-pump. All the openings of the boiler are securely closed. The safety-valve, which is loaded to the required test-pressure, is kept raised till the boiler is completely filled with water. Then, after closing the

safety-valve, the pump is worked till the steam-gauge indicates the test-pressure. The pump should deliver only a small quantity of water at each stroke, and must be worked carefully as the pressure rises, in order to avoid jarring the strained boiler and producing a sudden rise of pressure beyond the limit of the test-pressure. Some engineers close the safety-valve before the boiler is quite full of water, and so retain a quantity of air to act as a cushion when the pressure is applied by the pump; but when this enclosed air escapes through leaky seams and rivets no marks indicating such leaks are left on the plates.

When a boiler is connected with a high steam-drum the difference of the pressures at the top of the steam-drum and at the bottom of the boiler, equal to the weight of a column of water of corresponding height, may be a considerable quantity. The rules and regulations of the Board of Supervising Inspectors of Steam-vessels provide that, "in applying the hydrostatic test to boilers with a steam-chimney, the test-gauge should be applied to the *water-line* of such boilers."

The test should be applied before the boiler is painted and while every part is exposed to view. New boilers should be tested before they leave the boiler-shop. The boiler is placed on blocks so that the bottom may be inspected, and the furnace and connection doors are kept wide open. Every part of the boiler is watched and carefully examined while the pressure continues, to discover any leaks in rivets, seams, or tubes, or through cracks in the plates, and any signs of bulging of stayed surfaces or of collapse of flues. Leaky tubes, rivets, and seams are marked, and are calked after the boiler has been relieved of the pressure. Flat stayed surfaces and flues should be accurately gauged before and during the test.

"After the test-pressure has been maintained some time the measurements previously obtained should be checked, and any extension, distortion, bulging, etc., carefully noted. Then again, when the pressure is relaxed, which may be done suddenly, it should be ascertained whether any changes of shape that may have been found are permanent or not. If there be any permanent enlargement or distortion, even of the slightest degree, it should be satisfactorily examined to decide whether it is due to the elastic limit of the material having been exceeded or to malconstruction. There are cases, as, for instance, with flat surfaces, where a permanent set might take place, and which would be quite safe at the ordinary working pressure. This is especially the case with stayed surfaces, for it seldom happens that each stay in a series takes its due proportion of load until the stays have been stretched or the plates distorted by the pressure.

"But cases of a permanent flue-tube distortion or flattening must always be treated

with the greatest caution, since the change of shape is liable to become aggravated on a subsequent application of the same or even a less pressure. In all cases where a permanent set is discovered the test should be repeated again and again, if necessary, to ascertain if the set becomes increased." (*Wilson.*)

Time is an important element in boiler-tests. A boiler which bears a momentary pressure without apparent injury may burst with the same pressure continued through half an hour. No boiler should be considered safe if unable to bear the test-pressure for a considerable length of time. The test-pressure should always be maintained at least long enough to enable the inspector to make a thorough examination of all parts of the boiler.

"Want of tightness in the joints is often revealed by leakage only after the pressure has been applied for some time. In explanation it may be stated that the steam or water leaking from a joint does not always find its way between the plates immediately opposite the point of issue, but the actual source of the leakage, as we may call it, is at some point perhaps several inches distant, whence it requires a considerable time to force its way to the point where it makes its appearance. There can be no doubt that, from the manner in which boilers are usually put together, the internal pressure is not equally resisted by all parts of the shell, and produces an undue and often very severe strain on one plate or portion of a plate. This is probably the cause of many leakages that occur, and which only '*take up*' after the plate becomes stretched and relieved of the extra strain, and it is, therefore, advisable in testing to allow the pressure to act long enough to stretch such weak portions. . . .

"It is often much more difficult to keep a boiler perfectly tight and free from oozing at the rivets, plate-edges, stays, and tube-ends under a very high water-pressure than under an equal pressure of steam. This is probably owing to the fact that the high temperature in the latter case tends to close the joints, and with certain kinds of water any slight oozing is found to take up by the opening becoming closed with deposit or corrosion which is induced by the high temperature." (*Wilson.*)

Cold water is generally used in testing boilers. Some engineers advocate the use of hot water, because the expansion of the metal due to the higher temperature brings the different parts of the boiler more nearly under the conditions of stress which obtain when the boiler is in actual use, and because at low temperatures iron is more easily injured by strains. The water should, however, not be so hot as to be liable to cause injury by scalding in case of serious leaks, or to interfere with a thorough examination of the boiler within the furnaces and connections as well as outside. The effects produced by the uniform expansion of the whole boiler when hot water is used are, how-

ever, very unlike the effects produced by the local expansion of the parts in immediate contact with the fire and hot gases.

Boilers have been tested by filling them completely with water and lighting a fire in the furnaces, the pressure being produced by the expansion of the water. (*See Specifications of Boilers of U. S. S. Miantonomoh and class, section* 10, *chapter* vii.) It is claimed that with this method the increase of pressure is much more gradual than that produced by a pump, and that the conditions of actual practice, as far as differences of temperature are concerned, are at least approximately obtained. But a careful examination of the furnaces and back-connections is not possible with this method.

According to Wilson, it is not an unfrequent practice in England to test new boilers by steam under a pressure one and a quarter or one and a half times greater than the working pressure. It is argued that this is the only method by which the same conditions of strain can be produced as obtain when the boiler is worked. But this practice is to be condemned, not only because it is dangerous, but because it renders a careful examination of the furnaces and back-connections, while the pressure lasts, impossible.

Boilers that have been tested with water-pressure should be tested under steam to their working pressure, in order to prove their tightness after they have been located and connected in the vessel, and before their shell has been covered with felt or other non-conductive material. Every leaky seam, rivet, or tube should be made tight before the boiler is finally accepted for service.

2. Inspection of Boilers.—The testing of boilers by hydraulic pressure has to be regarded merely as an auxiliary means for ascertaining the strength and workmanship of a boiler; it should never be considered as making a careful examination of every accessible part unnecessary. Boilers which are faulty in design, or built of inferior material, or have bad workmanship put on them may stand the hydraulic test, but, under the varying and continued strains of actual practice, they will sooner or later develop weaknesses which seriously impair their life and safety. Grave defects may be hidden from view after a boiler is built so that they cannot be discovered by the closest scrutiny; therefore the inspection of boilers should commence with the process of construction, and should be repeated frequently during the lifetime of the boiler.

Section 4418 of the 'Revised Statutes of the United States' provides that "the local inspectors shall inspect the boilers of all steam-vessels before the same shall be used, and once at least in every year thereafter. They shall subject all boilers to the

hydrostatic pressure, and shall satisfy themselves by thorough examination that the boilers are well made, of good and suitable material, etc."

The regulations of the Board of Trade (English) for the survey of marine boilers provide that, when a boiler is not open to inspection during the whole period of its construction, the factor of safety for cylindrical boilers is to be increased 27.5 per cent. (see section 3, chapter ix.); that special attention should be paid to the survey of superheaters, which must be inspected inside and out; that the hammer-test should not be relied on entirely for superheaters, but that the plates should be drilled occasionally.

When boilers for United States naval vessels are built under contract at private establishments inspecting engineer officers are detailed to watch their construction, and to see that they are built in strict conformity to the drawings, and that the material and workmanship are of the best quality and in accordance with the specifications.

The attention of inspecting officers is to be directed especially to the following points:

All the material must be of the proper quality, without flaws, and of the prescribed dimensions. It is not an uncommon practice with boilermakers to use plate-iron of an inferior quality for the internal parts of a boiler, which are hidden from view when the boiler is finished.

Flanged plates must show no cracks or signs of laminations. Cracks extending from punched holes to the edge of the plate, or from hole to hole, are dangerous sources of weakness, and frequently indicate an inferior iron. Cracks are often produced in a row of rivets by drifting.

When the rivet-holes in a seam do not come fair they should not be corrected by drifting; nor is the use of smaller rivets in half-blind holes to be permitted. When the half-blind holes of a seam are corrected by punching or drilling so much of the metal may be cut away that the strength of the joint is seriously impaired, or that the holes can be closed only imperfectly by the rivets.

All plates drilled in place must be taken apart, and the burr must be removed from all drilled holes.

When plates are cut too small the boilermaker often tries to correct the mistake by punching the holes of the seams closer to the edge of the plates. All laps must be of the proper width, and the joints of contiguous plates must be placed as far as possible apart.

When the laps of plates do not lie close together the boilermaker often tries to cor-

rect or hide the evil by excessive calking, or by the insertion of pieces of hoop-iron, or by filling the open space with cement of cast-iron borings mixed with sal-ammoniac. By these means the bad workmanship may be concealed during the cold-water test, but it will cause trouble sooner or later under steam.

The edges of all plates should be planed or chipped fair before calking.

See that the proper width of water-spaces is maintained between the shell of the boiler and the back-connections, and that there is sufficient clearance between the flanges or strengthening-hoops of cylindrical furnace-flues and adjoining parts.

The tube-holes must be bored of such a size that the tubes fit them exactly. The tube-ends must not be expanded excessively, and must show no cracks after being expanded. The tube-ends should project at least $\frac{1}{8}$ inch beyond the tube-plates.

In the boilers built by contract for a United States naval vessel several tubes had been cut too short. To hide this defect short pieces of tube, turned down to a thin edge at one end, had been inserted in the back end of these tubes; the tubes and ferrules had then been expanded together and the projecting end of the ferrules beaded over. This work was so neatly done that the piecing of the tubes could not be detected by the eye, and the tubes showed no leaks under the cold-water pressure, but the continued leaking of the tubes under steam led to the discovery of their dangerous condition.

In the same boilers the pin-holes in the T-ends of several braces did not come fair with the holes in the angle-irons riveted to the shell of the boilers. Smaller bolts had been used to connect the braces to the angle-irons, and several bolts had been omitted entirely.

The bolts or pins of braces must fit the holes exactly, and must be secured by nuts or cotters. The T or angle irons to which the braces are attached must be securely riveted to the shell. Their rivet-holes must show no cracks, and their bolt-holes must not come too close to the edge of the flange. The long braces must be of equal tension; they must be straight, not bent to clear anything. Examine especially the stays running across the boiler between horizontal tubes to see that there is no danger of their bearing against the tubes. The holes of stay-bolts must come exactly opposite each other in both plates.

The explosion of the boiler of the U. S. S. *Chenango*, in 1864, was due to the omission of several braces.

See that no pieces of wood or iron have been left inside the boiler under and between the furnaces; that the valves open and close freely; that no pipes are closed by blank flanges; that the gauge-pipes are not closed by putty or rubber packing.

After the hydraulic test the boiler should always be examined inside to see whether the braces or their fastenings show any signs of having been unduly strained.

The periodical examination of boilers which have been in use is directed to the discovery of leaky tubes, seams, rivets, and stay-bolts ; of cracks and blisters, and of the distortion of plates by overheating ; of the accumulation of scale between the tubes and on the furnace-crowns, and of loose scale and dirt in the water-bottoms. The extent of corrosion of rivet-heads, of braces and their fastenings, and of plates must be carefully investigated.

The *hammer-test* is much relied on in examining old boilers. The plates are tapped lightly with a hand-hammer, and from the sound given out and the rebound of the hammer conclusions are drawn as to the thickness and soundness of the plates. In making this test the influence of the more or less close proximity of stays, angle-irons, or gusset-plates on the vibrations and springiness of plates must be taken into consideration.

When the thickness of plates appears doubtful a small hole is drilled through them.

3. Trials of Boilers.—Experiments on the evaporative power of boilers are, in general, of two kinds, being designed to determine either the greatest weight of water which the boilers are capable of evaporating in a unit of time, or the weight of fuel required for the evaporation of a given weight of water.

Numerous experiments, made under the direction of the Bureau of Steam-engineering of the United States Navy Department, to determine the relative evaporative efficiency of different types of boilers ; the influence of changes in the proportions of grate-surface, heating-surface, and calorimeter, and in the rate of combustion, on the evaporative efficiency of boilers ; and the value of different kinds of fuel for marine boilers, have been described by Isherwood in 'Experimental Researches' and in the various reports submitted by the boards of United States naval engineers charged with the conduct of these experiments.

In all such experiments the quantity of water fed into the boiler, the weight of fuel actually burnt and the weight of refuse matter of the fuel remaining unconsumed, the pressures of steam and of the outside air, and the temperatures of the feed-water, steam, external air, and chimney-gases should be carefully measured with accurately-tested instruments, and the observations noted at regular intervals. The firing must be done by experienced men and in a uniform manner. The fuel must be of a known and uniform quality. All conditions affecting combustion and evaporation in any manner must be carefully recorded. Foaming must be guarded against. To prevent leakage of steam or water the boiler must be tested under steam and water pressures before the experi-

ment commences, and the boiler itself and the joints of all its pipes and valves must be made perfectly tight.

Sometimes the steam generated in a boiler experiment is utilized in working an engine, and the weight of water evaporated is deduced from indicator diagrams taken at intervals during the trial. This method gives, however, no reliable results, since the loss of steam by condensation and leakage in the cylinders, valves, and pipes varies greatly under different conditions of the mechanism and with the manner of working the engines.

Errors resulting from leakage, foaming, and radiation will generally be diminished by evaporating the water under atmospheric pressure.

The longer the time during which the experiment is continued, the less is the final result affected by accidental disturbing elements and by inaccuracies of measurement and errors of observation.

Each boiler experiment conducted under the direction of the Bureau of Steam-engineering lasts, if possible, from 24 to 72 consecutive hours. The shorter the duration of the experiment, the shorter should be the intervals of time between the recorded observations.

For the sake of comparison the results of experiments on the evaporative efficiency of boilers are to be reduced to a uniform standard. For this purpose it is convenient to calculate the weight of water of a fixed temperature (either 100° or 212° Fahr.) which would be evaporated under a fixed barometrical pressure of the atmosphere, provided the same number of units of heat were communicated to the water under these conditions as were transmitted to the water in the boiler per pound of fuel, or of combustible matter of the fuel, consumed per hour.

The following extract from the 'Report on the Murphy Grate-bar,' by a board of United States naval engineers, June 25, 1878, gives a description of the usual method pursued in making the numerous boiler experiments which have been carried on under the direction of the Bureau of Steam-engineering:

"Before commencing the experiments the blow-off pipe was removed and a plate bolted across the aperture. This pipe was the only means through which water could escape from the boiler. A temporary steam-escape pipe of 7½ inches inside diameter was bolted on the top of the steam-drum, giving a straight discharge to the steam. The safety-valve, of 5 inches diameter, was removed from its chamber, and the permanent escape-pipe attached to it was used in addition to the temporary escape-pipe. . . .

"The feed-water, previous to entering the boiler, was accurately measured in two covered tanks placed on the hurricane or upper deck of the vessel. One of these tanks

discharged, by measurement, 54.67535 cubic feet of water, and the other discharged 47.59028 cubic feet of water at each delivery. The two tanks were connected by a pipe at their bottom, and in this pipe were two stop-cocks, one at each tank. From the centre of the pipe connecting the tanks another pipe was carried vertically downward 15 feet to the check-valve near the bottom of the boiler, so that the feeding of the boiler was effected by gravity, the quantity of water entering being regulated by the stop-cocks in the connecting-pipe. The tanks were supplied with lake-water by a small steam-pump worked with steam from a donkey-boiler.

"All the coal consumed was carefully weighed on a tested platform-scales in quantities of 182 pounds at each weighing. The refuse from this coal in ash, clinker, soot, etc., was similarly weighed and in the dry state.

"At the end of each experiment the furnaces, smoke-connections, flues, and tubes were swept clean of soot and ash, which were weighed, and their weight added to that of the refuse withdrawn from the furnaces and ashpits.

"In commencing an experiment the water in the boiler was brought to the boiling-point under the atmospheric pressure by wood alone, which was then allowed to burn down to the embers required for igniting the coal. No account was taken of the weight of wood thus consumed. The water-level in the boiler was now adjusted to the proper height in the glass water-gauge, the time noted, the coal fired, and the experiment held to commence. Each experiment was ended with the water in the boiler at the same level as at the commencement, and with the fires entirely burned out. It was intended that each experiment should last twenty-four consecutive hours, and from this duration none varied more than a few minutes. . . .

"One machinist was stationed at the tanks to note the time each was discharged and to report it to the engineer of the watch. Another was stationed in the fire-room to see the firing properly performed. A third was stationed at the scales for weighing the coal and its refuse. The watches were four in number, of six hours' duration each, and were superintended by the members of the board and the two engineer officers of the *Michigan*, who personally weighed the coal and its refuse, and kept a log, or tabular record, in the columns of which were entered hourly the kind of breeze blowing, the height of the barometer, the steam-pressure in the boiler, the pounds of coal thrown into the furnaces, the pounds of refuse in ash, clinker, etc., withdrawn from the furnaces and ash-pits, the temperature of the air on deck and in the fire-room, the temperature of the feed-water in the tanks, and the temperature of the gases of combustion in the chimney. This last temperature was obtained by means of a metallic pyrometer placed permanently in the base of the chimney, with its index outside."

The following description of an approximate method for determining the temperatures of the gases in the uptake of a boiler is taken from the 'Report on the Ashcroft Furnace-doors and Grate-bars,' by a board of United States naval engineers, March 27, 1878:

"The best approximation to the temperature of the gases of combustion in the boiler-uptakes that could be made was to place on little wire tripods small fragments of tin, lead, zinc, and antimony, and then insert these tripods into the mouths of the tubes at their uptake ends; the pieces of metal being at about the axes of the tubes and wholly surrounded by the escaping hot gases of combustion, the tripods touching the tubes at only three points. The melting-points of these metals may be taken approximately at 450°, 650°, 750°, and 850° Fahr.; and it is obvious that if one of them were found melted, and the next not melted, the temperature of the gases of combustion passing over them must have been somewhere between the respective melting-points. In this manner two limits of temperature are found at about 200° Fahr. apart, as an extreme, the mean perhaps not varying too widely from the truth for practical purposes. Three tripods were placed in the top row of tubes, three in the middle, and three in the bottom row of the tubes of each furnace—one tripod in the next to the corner tubes of each of these rows, and the third in the middle tube of the row; but the mean of all the approximate temperatures thus found cannot be assumed as the mean temperature of the whole mass of escaping gas, because the velocity of this gas varies much through the different tubes, being greatest through the top row, least through the bottom row, and intermediate in the rows between. The melting-points of the metals, though they furnish only indications of the temperature, prove the enormous difference in the temperature of the gases of combustion escaping from the top and bottom rows of tubes separated by a vertical distance of but a few inches—a difference sometimes as great as 300° Fahr."

To eliminate the errors due to inaccuracies in observing the steam-pressure, to superheating of the steam, and to the presence of unvaporized water in the steam escaping from the boiler, the whole of this steam may be led to a surface-condenser, the weights and temperatures of the water of condensation and of the condensing water before entering and after leaving the condenser measured, and, from these data, the units of heat actually present in the steam may be calculated. This method was used in the trials of steam boilers at the Fair of the American Institute in 1871.

In other instances the quality of the steam has been determined at regular intervals during the trial by introducing a portion of the steam into a calorimeter, where it was employed to heat a known quantity of water. This method was used in the boiler-tests at the International Exhibition, Philadelphia, 1876. A tank containing a known

weight of water of a known temperature was set on scales. Into this a sufficient quantity of steam was admitted to raise the temperature of the water a certain number of degrees. From the differences of the weights and temperatures of the water in the tank before and after the admission of steam the number of units of heat in, and the weight of, the steam were found.

CHAPTER XVII.

MANAGEMENT OF BOILERS.

1. Getting up Steam.—When the order is given to get up steam commence closing the boilers as soon as possible, so that, in case the joints of the manhole or handhole plates should be found to leak after the water is run up in the boiler, the latter can be emptied and the joints remade without delaying the starting of the fires. Before closing the boiler satisfy yourself that all the braces are secured, and that no articles used in repairing or cleaning the boiler have been left inside.

Rubber gaskets, manufactured in continuous rings of the size and shape required, are used almost universally for making the joints of manhole and handhole plates. When gaskets are cut out of sheet-rubber they are generally made in several pieces with dovetailed ends, in order to economize material. The gasket must fit accurately around the projecting rim of the plate and lie perfectly flat on the flange. When the flange of the plate, and the ring around the manhole on which it seats, are smooth and level the joint can be made tight without using white or red lead, which makes the rubber hard and brittle. In removing the plate the rubber gasket is apt to stick partly to the boiler and partly to the plate, and thus become injured. This may be prevented by coating the gasket with black lead on the side in contact with the boiler. A mixture of black lead and tallow is also used for this purpose and to soften the gasket, but the tallow rots the rubber. A coating of white lead is frequently put on the flange of the plate, so that the gasket may stick to the plate in preference to sticking to the boiler. When a manhole-plate is found to leak after steam has been raised it may often be made tight by driving thin, flat wedges of soft pine wood between the projecting rim of the plate and the edge of the manhole. The sides of these wedges should be slightly bevelled, and adjoining wedges should overlap one another.

All the valves and cocks connected with the boiler should be examined before getting up steam, to make sure that they can be operated freely. The steam stop-valves are closed, but it is well to ease them off their seat slightly, else it may happen that, in consequence of the unequal expansion of the valve-disc and chamber when steam first begins to form, the valve be jammed in its seat. The safety-valves are

raised and kept open till steam begins to form, to allow the escape of air from the boiler.

The boilers are filled either by opening the bottom blow-valves and letting the water run in from the sea, or by pumping water in through the check-valves. When the water is taken from a tank or hydrant on shore it may be run in by means of a hose through a manhole on top of the boiler or through the safety-valve. Boilers should be filled with warm water when practicable. The height of the water within the boiler before it has risen to the level of the water-gauges may be found, when the temperature of the entering water is different from that of the boiler-shell, by applying the hand to the shell and judging by the feeling. Or it may be found by tapping the shell with a hammer and judging by the different sounds produced at places where the boiler is filled and empty. To know whether the water is rising in the boiler when it enters through the bottom blow-valve, open the water-gauge cocks and apply the hand or a lighted lamp to the opening; the rising water will expel the air through the opening.

Before charging the furnaces with fuel see that the grates, bridge-walls, and ashpits are quite clear of ashes, clinker, etc., that the tubes are unobstructed, and that no articles are left in the front or back connections. Then close the uptake-doors. Remove the hood from the chimney and open the damper. Hoist the chimney and secure it. Leave the stays slack, and defer their adjustment till after the fires are well started and the pipe has become hot; but never set them up quite rigid.

In charging the furnaces the back of the grate is covered evenly with a thin layer of small coal; on the front of the grate some billets of split wood are placed side by side, the ends of which are supported by a couple of pieces laid crosswise the furnace. A few shovelfuls of coal are thrown on the wood, and some small kindling-wood, shavings, oily rags, or other inflammable substances are placed at the furnace-mouth below the layer of wood.

When the water has risen to the proper height in the boiler the kindling-wood in the furnaces is lighted; the furnace-doors are kept slightly open and the ashpit-doors partly closed till the whole mass of wood has caught fire. More coal, broken up in small pieces, is thrown on the burning mass, and the furnace-doors are closed and the ashpit-doors opened. When the heap of coal on the front of the grate has become incandescent it is partly pushed back; more coal is added, which is likewise pushed gently back as soon as it becomes incandescent. This operation is repeated till there is a sufficient mass of burning coal on the grate.

Sometimes, especially in very damp weather or when the air meets with many obstructions in flowing to the ashpits, it may be necessary to produce an artificial draught

in the chimney in order to start the fires. By placing some burning shavings in the uptake, and then closing the uptake-doors quickly, the column of air in the chimney is heated and an ascending current is produced.

When it is necessary to raise steam with all possible despatch for a great emergency the fires may be lighted while the water is still rising in the boiler, as soon as the heating-surfaces are barely covered with water, and the water is then allowed to rise only to its lowest admissible level in the gauge-glass. By using bituminous coal or greasy or tarry matter in starting the fires the time required for getting up steam may be greatly shortened. By this means steam may be raised from cold water in large marine boilers in a comparatively short time. The unequal expansion of the parts in contact with the fire and the products of combustion, and of the boiler-shell, causes very injurious strains, especially when the fires are urged from the beginning while the water is still cold, which should, therefore, be avoided except in cases of great emergency. The fires should be allowed to burn up slowly by being kept banked while the water is being heated. Under ordinary circumstances not less than three hours should be allowed for getting up steam. With very long cylindrical boilers, like the double-end boiler represented on Plate XV., it is advisable to allow even six hours for this purpose.

A great saving of wood may be effected, when there is no hurry in getting up steam, by starting fires with wood at first only in the alternate furnaces of the boiler, and then transferring some of the incandescent coal to the other furnaces, the grates of which have been previously covered with a thin layer of coal.

As soon as a light column of steam rises from the escape-pipe or issues from the open gauge-cocks the safety-valves are closed, the stop-valves opened, and the boilers put in communication with each other.

2. Firing.—The thickness of the bed of fuel on the grate must be regulated, according to the kind, quality, and size of the fuel and to the force of the draught, in such a manner as to ensure the passage of the proper quantity of air evenly distributed through the grate.

With ordinary chimney-draught, giving a rate of combustion of from 12 to 16 lbs. of coal per square foot of grate per hour, a fire of *anthracite coal* of *egg-size* may be carried from 5 to 6 inches thick. A thin fire, under otherwise equal conditions, offers less resistance to the passage of the air through the grate, and is thus favorable to a rapid rate of combustion. When the lumps of coal are of smaller size the fire may be carried relatively thinner; but when the fire is less than four inches thick a large grate cannot be kept evenly covered, and too much air will pass through the grate. When *bituminous* coal is used with a rapid rate of combustion the fire must be carried thicker

than with anthracite coal, else the grate cannot be kept covered evenly ; this is especially the case with free-burning semi-bituminous coals.

With a forced draught the thickness of the fire is to be increased, and the size of the lumps of anthracite coal should be diminished at the same time.

The furnaces should be fired regularly with moderate charges. When much coal is thrown into the furnace it will take a long time to kindle ; but when the charges are very small and oft repeated the frequent opening of the door causes a waste of heat. Anthracite coal may be fired at intervals of from 15 to 20 minutes, according to the rate of combustion. Bituminous coal, especially when it is of small size, should be fired more frequently, every 10 or 15 minutes, because the evolution of the hydrocarbon gases as each charge is thrown into the furnace makes a large quantity of heat latent, and the temperature of the furnace would vary greatly if a large mass of coal was introduced into the furnace at one time. Each charge of coal should be spread in an even layer over the grate, and, as the bed of fuel burns away irregularly, it has to be levelled.

When the coal cakes much the fire has to be broken up from time to time to afford a passage to the air through the grate. The several furnaces of a boiler or set of boilers should be fired and worked in rotation, so that, if possible, no two furnace-doors are open at the same time. The coaling and working of the fires must be done as rapidly as possible to limit the inflow of cold air in a mass through the open doors to a minimum.

When the fires are kept thin while the draught is active, or when the fires are not kept properly levelled, the air rushes sometimes with great violence through the uncovered parts of the grate, producing a roaring noise and severe concussions of the boiler. This phenomenon is called *back-draught.* By partly opening the furnace-doors or closing the ashpit-doors the draught is generally checked sufficiently to stop the violent rush of air, but to remedy the evil the fire must be levelled or carried a little thicker.

When the incandescent fuel throws a uniform bright light below the grate it indicates that the fires are clean and burning actively. When the ashpits are dark, either totally or in parts, it indicates an accumulation of ashes or clinker on the grates. To clear the air-passages the hook-bar is run through the interstices of the grate from the ashpit, and when much difficulty is experienced in moving the hook-bar back and forth between the grate-bars it indicates the formation of clinker. Clinkers adhering to the top of the grate-bars are detached by means of the slice-bar introduced through the furnace-door, and are then removed from the furnace. Ashes and cinders are apt to accumulate in the corners of the furnace; such places must be cleaned out and the

whole grate must be kept covered with live coal. When the coal is friable it should be disturbed as little as possible with the slice-bar, to avoid the loss of small coal falling unburnt through the grate.

When the accumulation of ashes, cinders, and clinker on the grate becomes so great that they cannot be removed by pricking and slicing, the fire must be thoroughly cleaned by hauling all refuse matter from the furnace, leaving a clean bed of incandescent coal on the grate. This cleaning should be done at regular intervals, generally not exceeding twelve hours, but depending on the amount and kind of the refuse matter contained in the coal. That the cleaning may be done quickly and thoroughly the fire should not be very heavy, but it should have a sufficiently thick layer of incandescent coal on top to cover the grate completely after the refuse has been removed. The fireman pushes back the top layer of incandescent coal from the front half of the grate and hauls the mass of refuse below it from the furnace, cleaning the grate entirely. Then he hauls all the clean coal from the back of the furnace to the front of the grate; he works the mass of ashes and cinders at the back through between the grate-bars, and hauls the larger of pieces of slate and clinker out of the furnace over the heap of coal in front. The clean coal is then spread evenly over the grate and covered at once with a thin layer of fresh fuel.

Some firemen, instead of cleaning first the front and then the back of the fire, clean the two sides of the furnace in succession, using the slice-bar to move the top layer of clean coal from the side to be cleaned to the other side.

The *slack* of anthracite coal can be burnt only when mixed with a certain proportion of lump-coal. The lumps should never be larger than a cube of three inches a side.

The dust of bituminous coal may be burnt by mixing it with water so as to form a cohering mass or thick paste. The evaporation of the water mixed with the coal absorbs much heat, but without it the dust would fall through the grate or be carried into the flues by an active draught, proving thus a total loss.

The friable, free-burning semi-bituminous coals are frequently mixed in equal proportions with caking coals, in order to bind the small particles of the former together and prevent their falling unconsumed through the grate.

Many kinds of bituminous coal require special methods of firing, in order that their gaseous products may be completely consumed and that the production of smoke may be prevented. When a fresh charge of coal is thrown upon the fire the first effect produced, as it becomes heated, is the evolution of a mass of hydrocarbon gases, which make latent a large quantity of heat and require a larger quantity of air for their complete combustion than the remaining solid portion of the coal or coke. On this account

the air-admission through the door into the furnace, or through the bridge-wall into the combustion-chamber, may be regulated by registers, which are opened after a fresh charge of coal has been thrown upon the fire, and closed when the evolution of hydrocarbon gases ceases—that is to say, when the coal burns without flame.

When the furnaces are wide *side-firing* may be employed, which consists in throwing each new charge of coal alternately on either side of the fire, so that the evolution of hydrocarbon gases takes place only on one half of the grate, while on the other half the coked coal of the previous charge is burnt.

Some kinds of free-burning semi-bituminous coal are burnt to best advantage by piling each fresh charge up on the dead-plate at the front of the grate, where the volatile ingredients of the coal are expelled by the heat radiated from the incandescent fuel. As these gases pass through the furnace and mix with a sufficient quantity of air, which passes in excess through the grate, they ignite and are completely consumed. As soon as the mass of coal on the dead-plate becomes converted into coke it is pushed back and spread over the grate.

When wood is to be used as fuel in a furnace designed to burn coal the grate has to be lowered to increase the capacity of the furnace, and the spaces between the bars should be increased in width by omitting a number of grate-bars.

3. Management of Boilers under Steam.—That the boilers may furnish a uniform supply of steam the fires must be supplied with fuel and cleaned in regular rotation, as described in the preceding section, and the water in the boiler should be kept at nearly a uniform height. When the opening of the check and blow valves is properly adjusted the feeding and blowing may be kept up continuously. The water-gauge glass is generally located in relation to the tubes and back-connections so that a proper level of water is maintained when the glass is kept about half-full of water. Previous to cleaning a fire the water may be allowed to rise a few inches above the usual level, so that during the process of cleaning the fires, and till they have been brought again to their normal state, the supply of feed-water may be diminished.

When bituminous coal is used as fuel the tubes must be swept at regular intervals, about once in twenty-four hours or less frequently, according to the greater or less tendency of the coal to form deposits of soot.

In order to increase the evaporation to a maximum diminish the quantity of water blown out and increase the temperature of the feed-water as much as practicable; secure an ample air-supply by turning the fire-room ventilators and windsails to the wind; keep the ashpits wide open and clear of ashes, and the fires clean; use coal of about egg-size and free of slack, when the fuel is anthracite; and regulate the thickness of the

fires according to the force of the draught and the kind, quality, and size of the fuel. The boilers of naval vessels are generally provided with a steam-jet in the chimney for the purpose of increasing the draught. It should be borne in mind that with a given boiler the rate of combustion cannot be increased advantageously beyond a certain limit, on account of the decrease of the *economic* evaporative efficiency of the boiler; that the efficiency of the boiler may be greatly diminished by foaming with an increased evaporation; and that the available quantity of steam furnished by a boiler may be actually diminished when the rate of combustion is increased by forcing the draught. (*See section* 6, *chapter* xii.)

When only a fraction of the boiler-power is used all the openings of the uptake, furnace and ashpit doors of such furnaces as are not in use must be closed tight to prevent the inflow of cold air. Often it is advantageous to keep all the furnaces in use, but to diminish the effective grate-surface by covering the back of the grate either with a thick layer of ashes or by a wall of fire-brick built up to the height of the bridge-wall. The latter plan should be adopted only in case the reduced boiler-power is to be used for long periods during which no necessity will arise for using full boiler-power.

When the boilers are not required to work up to their full power fuel may be economized by burning a greater proportion of slack or coal-dust, and by sifting the ashes and burning a portion of them containing particles of unconsumed coal.

Banking a fire means to pull the coal together in a heap, leaving a part of the grate uncovered. By this means the combustion is greatly retarded, and the cold air flowing in through the uncovered part of the grate checks the evaporation. When the boilers are not to be used for a certain length of time, but fires are to be kept in them to keep the water hot, the fires should be banked and covered with a layer of ashes or slack, and the ashpit-doors and the damper should be nearly closed.

When the steam-supply is to be temporarily diminished while the boiler is in operation some fires may be banked, and the draught may be checked by closing the ashpit-doors and the damper and by opening the uptake and furnace doors. The opening of the furnace-doors should be avoided, if possible, because the cold air, rushing into the furnaces and striking the highly-heated plates, causes sudden and unequal variations of temperature, which produce local strains resulting frequently in permanent injuries to the boiler.

When the engines are stopped suddenly, but the boilers have to be kept ready for starting again shortly, the formation of steam has to be checked as quickly as possible; to this end open the furnace and uptake doors, close the ashpit-doors and dam-

pers, uncover a part of the grate, increase the feed-water supply and the quantity of water blown out; utilize the steam for distilling or other useful purposes. When the steam-pressure rises to the limit allowed the safety-valve has to be raised. United States naval boilers are frequently provided with a *bleeding-valve*, by which an excess of steam may be discharged from the boiler into the condenser, instead of being allowed to escape through the safety-valve.

The safety-valve should always be opened gradually. When it is suddenly opened wide the steam, rushing from it with great violence, is apt to carry a mass of water with it, which falls in a shower from the top of the escape-pipe on the deck. When the water-capacity of the boiler is small this sudden loss of water may even cause some parts of the heating-surfaces of the boiler to become uncovered.

In the indications of the water-level in the boiler by the gauge-glass proper allowance must be made for the oscillations and the list of the vessel, and the gauge must be tried from time to time to see that the narrow passages are not choked with sediment or scale. When the water-passage is clear, but the steam-passage is closed, the gauge-glass will remain completely filled with water. When, on the contrary, the steam-passage is clear and the water-passage is choked the water remains at a constant level in the glass without oscillating. The gauge-glass must be blown through from time to time by opening the waste-cock and shutting off the water and steam cocks alternately. If this does not clear the passages it is necessary to run a wire through them.

The indications of the water-gauges are frequently very uncertain and deceptive when the boiler *foams;* the water in the gauge-glasses rises and falls rapidly and in an irregular manner, and on opening the gauge-cocks a mixture of steam and water issues, producing a sputtering sound.

All boilers will foam to some extent when the rate of combustion exceeds a certain limit. But boilers with insufficient or low steam-room, contracted water-surface, and defective circulation are especially liable to foaming. In boilers with narrow water-spaces and a high rate of combustion the water is frequently lifted in a mass, so that the water-gauges indicate a steady level of solid water while the engines are in operation; but as soon as the supply of steam drawn from the boiler and the rate of evaporation are diminished the water falls suddenly to its true level, disappearing sometimes entirely from the gauges. In all such cases it is necessary to check the evaporation in order to stop the foaming; and it is frequently necessary to slow down the engines or open the furnace-doors from time to time for the purpose of finding the true level of the water in the boiler.

Vertical fire-tube boilers and horizontal cylindrical boilers of small diameter foam

frequently because there is too much water in them, in consequence of which their steam-room and the area of the water-level are simultaneously reduced.

Another cause of foaming is the presence of mud or dirt of a mucilaginous nature in the water, which may be recognized by the appearance of the water in the gauge-glass. Also, when a vessel enters a river in coming from the sea, or *vice versâ*, the boilers are liable to foam when they are fed directly with water from overboard. In all such cases it is advisable to change the water in the boilers as rapidly as possible by opening the surface blow-valves wide and feeding strongly.

In reducing the saturation of boilers the surface blow-valves should be used in preference to the bottom blow-valves, unless the vessel rolls so much that the former would frequently discharge steam instead of water.

When the water falls below its usual level in the boiler examine the feed and check valves to see whether they are open and in operation. The latter will be indicated by the clicking noise made by the check-valve as it rises and falls in its seat; also by the temperature of the pipe immediately below the valve, which should be comparatively cool to the touch. Close the blow-valves, and if the water continues to fall in the boiler it must be owing to a leak in the boiler. If no water enters through the check-valve, although the feed-pump is throwing water, the latter may escape through a leak in the feed-pipe, or all the water may enter some of the other boilers, or the relief-valve of the pump may be gagged or insufficiently loaded. If the pump does not throw any water it may be owing to air-leaks in the stuffing-box or in the suction-pipe, or because the valves or the piston are leaking, or because the feed-water is too hot. The feed-pump may get hot because the check-valves are leaking. When the valve is kept open by being jammed a slight jar produced by tapping the valve-chamber with a hammer is sometimes sufficient to seat it. When some matter has lodged under the valve and prevents its seating it may be washed away by a strong feed with the donkey-pump.

In case the water should suddenly disappear from the gauge-glass on stopping the engines, the safety-valve may be opened wide in order to cause the boiler to foam again and the water to be lifted sufficiently to cover the heating-surfaces; at the same time close the blow-valves and check the evaporation by opening the furnace and connection doors and by covering the fires. Do not put on the feed unless you are sure that the water has not fallen low enough to cause the plates to become overheated.

In case any part of the boiler should be discovered to have become red-hot in consequence of low water, or the furnace-crowns to be collapsing, do not open the safety-valve or change the working of the engines, and especially do not open the feed-valve, but haul the fires from the furnaces at once or cover them with wet ashes, and

then successively close the stop-valve, blow the water from the boiler through the bottom blow-valve, and open the safety-valve.

Leaks in a boiler under steam become manifest by a hissing sound and by the appearance of the issuing steam or water. Serious leaks in the bottom of a boiler may become known only by the falling of the water-level in the boiler, and by an increase in the quantity and in the temperature of the water in the bilge. All leaks should be closely watched, and, in case they are found to increase or cause serious inconvenience, the pressure in the boiler should be diminished, if the leaks cannot be stopped otherwise. Small leaks of water frequently stop of themselves by the gradual accumulation of salt deposited by the issuing water.

Leaks in the joints of manhole and handhole plates, and leaks caused by the blowing-out of a bolt or rivet in the boiler, or by small holes in the feed and blow pipes, may be temporarily stopped by driving into the holes causing the leaks slightly tapering plugs or wedges cut from dry, soft pine wood.

When a feed or blow pipe is split or cracked it must be tightly wrapped with stout cotton canvas painted with red lead on the side nearest the pipe, and closely bound with marline. Cut the canvas in long strips about 3 inches wide, and let each turn overlap the preceding one half its width. Wind the marline around it in such a direction as to tighten the canvas wrapping, and lay each turn close to the other, pulling hard to prevent its stretching or shifting afterwards.

Leaks in the boiler may sometimes be stopped temporarily by covering the defective place with a piece of plate-iron fitting closely to the surface and held firmly in position by means of wedges driven against the bottom or side of the vessel, or against the opposite wall of the boiler or of an adjoining boiler. To make the joint of the patch tight use either canvas painted with red lead, or putty made of white and red lead and stiffened by mixing it either with fine iron borings or with hemp chopped very fine.

When leaks appear in the furnace-crowns, the water issuing either from cracks in the plates or from the seams, it is best to haul the fires from the respective furnaces when the leaks are found to be increasing with continued use.

The leaks of tubes may be caused either by the defective joints of their ends or by holes or rents in the tubes. In the latter case the leak may be stopped by plugging the defective tube with a turned soft pine plug of very slight taper. These plugs are about 5 or 6 inches long, and are wrapped with canvas painted with white or red lead. For the front end of the tubes the diameter of the larger end of the plug is slightly greater than the internal diameter of the tubes, and the small end is swelled out by the water which penetrates the pores of the wood, and the plug is thus held tightly in the tube.

When the leak is not very large it is sufficient to plug the uptake end of return-tube boilers, so that the water does not run out through the uptake-doors and interfere with the working of the fires, but runs into the back-connections. A small leak may sometimes be stopped completely by securing a plug within the tube over the defective place. When the leak is so large that the water issuing from it would greatly impair the efficiency of the fire and cause a large accumulation of salt, which is not only difficult to remove, but, by closing a number of tubes, may seriously impede the draught of the furnace, both ends of the leaky tube have to be plugged. The back-connection end of the horizontal fire-tubes may be plugged without hauling the fires, by introducing from the front end of the boiler a plug with a long wedge inserted in a cross-cut at its outboard end, which butts against the back wall of the back-connection when the plug is in place, so that when the latter is driven home the wedge forces it tightly against the tube. Sometimes the plug itself is made long enough to reach to the back wall of the back-connection when it is home, and the wedge is inserted and driven in the end of the plug projecting within the tube. The part of the plug or wedge which projects within the back-connection soon burns away, but within the tube the plug is protected by the water which penetrates its pores. After the plug has been driven in the back end another plug is driven in the front end, as described above. It is, however, necessary to lower the steam-pressure greatly before commencing this operation.

Sometimes it may be necessary to enter the back-connection in order to plug a tube effectually. In such a case haul the fire from the furnace which is to be entered, and bank and cover up with ashes the fires in the other furnaces of the boiler. Open the surface-blow and pump water into the boiler from the sea, so as to reduce the temperature of the water in the boiler. Then open the safety-valve and give to the vessel a list to let the water run out of the front end of the leaky tube. After covering the grate, bridge-wall, and back-connection of the empty furnace with boards, bags, or old canvas, a man can safely enter the back-connection. Then the tube may be stopped up with a wooden plug in the same manner as described above for the front end of the tubes. Or both ends of the tube are covered with cup-shaped washers filled with stiff putty, and, to hold them in place, a stout iron rod is put through the tube, so that its ends, on which screw-threads are cut, project through the washers; the latter are then screwed up tight with nuts.

When a boiler is to be put out of use it is best to let it cool off gradually. To this end, after the fires are hauled from the furnaces, all the doors should be kept closed and the steam should be allowed to condense gradually in the boiler. When the pressure has fallen nearly to that of the atmosphere the safety-valve is to be raised and kept

open. When the temperature of the water in the boiler has decreased sufficiently the water may be pumped out of the boiler when the latter is provided with a valve and pipe-connection for this purpose, or the water may be allowed to run out into the bilge through one of the mudholes in the bottom of the boiler.

When the boiler has to be cooled off quickly for the purpose of cleaning and repairing it in an emergency, the water is blown out through the bottom blow-valve as soon as the fires are hauled. Previously the steam should be raised to the highest working pressure, so that the water may be blown out as completely as possible. A peculiar crackling noise in the blow-pipe, produced by the condensation of the steam as it comes in contact with the cold water, indicates that the boiler is empty. When the blow-valve is kept open after the steam-pressure has fallen so low that it no longer balances a column of water equal in height to the difference between the levels of the water in the boiler and of the sea-water, the latter will enter the boiler. This would be indicated by the sudden cooling of the blow-pipe. The height to which the water in the boiler has fallen may be found by sounding the boiler with a hammer. As soon as the blow-valve is closed the safety-valve is raised, and all the furnace and connection doors are opened and the manhole and mudhole plates are taken off to dry and cool the boiler. In case of urgency the boiler may be cooled quickly by filling it with cold sea-water after blowing the water out, afterwards running the sea-water out into the bilge.

Blowing a boiler down jars it severely, especially when the blow-valve is opened wide; and this is often the cause of leaks in the boiler and in the pipes connected with it. It should never be done except in cases of great emergency.

4. Foaming: its Causes, Effects, and Prevention.—*Foaming* or *priming* means that the water in the boiler is in a state of violent agitation, rising and falling rapidly in the form of waves, or that the steam is mixed with water in the form of spray. Foaming is a source of great inconvenience, and not unfrequently of danger, on account of the uncertain and wrong indications of the water-level given by the gauges; and, as the water is carried with the steam into the cylinders, it causes a serious loss of efficiency and may cause a breaking-down of the engines.

Foaming is made evident by the boiling-up or the rapid and irregular oscillations of the water in the gauge-glass, and by the sputtering sound produced as the mixture of steam and water issues from the gauge-cocks. When the water is carried over into the cylinders its presence is made known by a clicking noise caused by the partial collapse of the piston-rings, and, when the water is present in large quantities, by the thumping of the piston at each end of the stroke.

All boilers are apt to foam when the water contains much mud or dirt of a mucil-

aginous nature. Soda, introduced into the boiler to neutralize the fatty acids contained in the feed-water, often produces foaming. The various organic substances introduced into boilers to prevent the formation of scale are apt to produce the same effect. (*See section* 11, *chapter* xviii.) The engines of the English naval vessel *Hecate* were broken down by excessive foaming caused by the lime placed in her boilers to preserve them and not removed before getting up steam. When a vessel coming from the sea enters fresh water, or from a river enters the sea, the boilers foam frequently. In all such cases it is advisable to change the water in the boiler as rapidly as possible by opening the surface blow-valves wide and putting on a strong feed.

The plan of stopping foaming by covering the surface of the water in the boiler with a layer of oil or molten tallow injected through the feed-pumps is not to be recommended. It is not only an expensive remedy, but the decomposition of the animal or vegetable fats at high temperatures, and in contact with metals, produces fatty acids which are very destructive to boilers.

Boilers are liable to foam when they have an insufficient and low steam-room, a contracted water-surface, and such an arrangement of the internal parts as to render the circulation of the water defective. It may be assumed that any boiler will foam more or less when its evaporation exceeds a certain limit, so that the steam-bubbles rise so rapidly as to carry some of the water through which they pass along with them. For this reason some water-tube boilers are provided with deflecting-plates at the upper ends of the tubes, without which the water would be thrown in jets from the tubes into the steam-space. (*See figure* 2, *Plate* XXVIII., *and section* 10, *chapter* xi.)

When the steam, as it is generated, has to escape in large masses through very narrow water-passages separate channels must be provided for the descending water-currents, else the meeting of the two currents moving in opposite directions is very apt to result in foaming, or sometimes in *lifting the water*. The latter expression means that the steam does not rise, as it is generated, through the overlying mass of water, but accumulates on the heating-surfaces, so that water appears at a greater height in the boiler than would be the case if the steam and water occupied their natural positions. Under these circumstances the heating-surfaces which are kept bare of water are liable to become overheated, and the water-gauges give wrong indications of the quantity of water in the boiler. Whenever the evaporation is checked the water falls to its true level. Thus it frequently happens, in small boilers worked with a high rate of combustion, that the water disappears suddenly from the gauges which had indicated a moment before an ample supply of water in the boilers. The overheating of the metallic surfaces may cause the water, as it comes in contact with them, to assume the spheroidal

state, and its evaporation to take place in an intermittent, explosive manner, thereby producing rapid oscillations of the water-level or projections of water into the steam-space.

In *hanging water-tubes* the separation of the ascending and descending currents is effected by an inner tube. (*See section* 10, *chapter* xi.)

In the vertical fire-tube boiler represented in figure 1, Plate XXVIII., the internal annular tank, which serves as a steam-reservoir, separates also the ascending and descending currents; the steam rises from the crown of the furnace between the tubes, and the water flows downward in the annular space between the tank and the shell of the boiler.

In the ordinary marine boiler with the tubes arranged over the furnaces the great mass of steam generated on the furnace-crowns, in addition to the steam formed on the tube-surfaces, has to rise through the narrow spaces between the tubes; while in the locomotive type of boiler the steam escapes from the furnace-crowns and from the tube-surfaces directly to the steam-room. This difference in the arrangement of the heating-surfaces is the principal reason why the rate of combustion in marine boilers cannot approach remotely the rate of combustion common in locomotive boilers without producing violent foaming. To lessen this evil the circulation of the water in marine boilers should be facilitated by leaving wide, unobstructed passages between the nests of tubes of adjoining furnaces. Good results have been obtained in English boilers by separating these spaces, by means of removable plates, from the nests of tubes so that they may serve exclusively as passages for the descending currents of water flowing to the furnace-crowns. In the boiler designed for the U. S. S. *Palos* similar plates, reaching from the upper row of tubes to the furnace-crowns, were attached by means of socket-bolts to the cylindrical shell, leaving a space several inches wide between the shell and the plate. The introduction of circulating-tubes in the back-connections has also had the effect of lessening foaming in some cases.

In horizontal cylindrical boilers the water-surface and the steam-room both diminish rapidly as the height of the water-level is increased, and this circumstance renders this form of boiler especially liable to foaming. This effect is frequently produced when the water is allowed by accident to rise beyond a certain height in the boiler. In some cases it has been found advantageous to cut out the upper row of tubes and plug up the holes in the tube-sheets, so as to be able to carry the water lower in the boiler, the loss in evaporative power by the diminution of the heating-surface and calorimeter of the tubes being far less than the gain in efficiency due to lessened foaming. This plan was adopted in the boiler of the U. S. S. *Triana*, and, to make it possible to carry the water below the

top of the back-connection, a false top was built in the connection, and the space thus formed filled with plaster-of-Paris.

Whenever the steam-pressure is suddenly diminished by withdrawing a large quantity of steam from the boiler, the temperature of the water will be so much higher than the boiling-point corresponding to the reduced steam-pressure that a sudden evolution of steam, accompanied by violent ebullition, takes place. This effect is produced when the steam-room in the boiler is too small, or when the engines are suddenly started at a high speed or are racing, or when the safety-valve is all at once thrown wide open. In such cases the steam rushing violently to the opening may carry along with it a large mass of water, which rises as a wave over the surface of the water, and, when the steam-room is low, may be carried into the steam-pipe and flood the cylinders, or be projected from the escape-pipe. It is of little use to surround the opening of the stop-valves with deflecting-plates which are to throw off the mass of water carried up by the steam-current. The evil may frequently be corrected by drawing the steam equally from a large area by the use of perforated dry-pipes; or, if these cannot be applied, a second stop-valve may be placed on the boiler which takes steam at some distance from the original stop-valve. This plan is far more effective than merely enlarging the original stop-valve in order to diminish the velocity of the steam passing through its orifice.

In many cases it will be found necessary to increase the steam-room by the addition of a steam-drum. High vertical steam-drums have the advantage that the water held suspended in the steam is separated to a great extent from it before it can reach the top of the drum, from where the stop-valve should take the steam. (*See also section* 1, *chapter* xiii.)

Superheaters are efficient in correcting some of the evils of foaming by increasing the steam-room and by evaporating the water carried along with the steam. (*See section* 10, *chapter* iii.) It is, however, found that foaming causes frequently the rapid destruction of superheaters. (*See section* 3, *chapter* xiii.)

5. Constituents of Saline Matter in Sea-water.—The proportion of saline matter contained in the waters of different seas varies greatly. According to Dr. Marcet, the ocean of the southern hemisphere contains more salt than that of the northern hemisphere, the mean specific gravity of sea-water near the equator being 1.0277, or intermediate between that of the waters of the northern and southern oceans.

Dr. Ure gives the following proportions of saline matter in 1,000 parts (by weight) of sea-water from different localities: "The largest proportion of salt held in solution in the open sea is 38, and the smallest 32. The Red Sea contains 43; the Mediterranean,

38; the British Channel, 35.5; the Arctic Ocean, 28.5; the Black Sea, about 21; and the Baltic, only 6.6."

An analysis of the water of the English Channel at Brighton, made by Dr. Schweitzer, gave the following results—viz.: its specific gravity was 1.0274, and 1,000 parts, by weight, contained—

Water	964.74372
Chloride of sodium	27.05948
Chloride of magnesium	3.66658
Chloride of potassium	0.76552
Bromide of magnesium	0.02929
Sulphate of magnesia	2.29578
Sulphate of lime	1.40662
Carbonate of lime	0.03301
Total weight	1000.00000

An analysis of the water of the Mediterranean, made by Dr. Laurens, gave the following results—viz.: its specific gravity was 1.0293, and 1,000 parts, by weight, contained—

Water	959.06
Chloride of sodium	27.22
Chloride of magnesium	6.14
Sulphate of magnesia	7.02
Sulphate of lime	0.15
Carbonate of lime	0.09
Carbonate of magnesia	0.11
Carbonic acid	0.20
Potash	0.01
Total weight	1000.00

The amount of *carbonate of lime* contained in sea-water is insignificant. According to Bucholz, 100 parts of cold water are capable of holding in solution from .00416 to .00625 parts of carbonate of lime. The French chemist Cousté states that water loses entirely its power of holding this salt in solution when its temperature reaches a point lying between 285° and 300° Fahr. After being once precipitated the carbonate of lime is not redissolved when the temperature of the water is lowered.

When water contains an excess of carbonic acid the carbonate of lime is converted into an acid carbonate of lime, which is much more soluble in water. On the application of heat the acid carbonate loses a portion of its carbonic acid, and the neutral carbonate of lime is deposited in the form of a powder.

The solubility of *sulphate of lime* is, according to Regnault, a maximum at 95° Fahr., when 100 parts of water dissolve 0.254 parts of this salt. At 212° Fahr. 100 parts of water dissolve only 0.217 parts of this salt; and, according to Cousté, water loses completely its power of holding in solution the sulphate of lime when its temperature reaches a point lying between 285° and 300° Fahr. This salt is more soluble in dilute solutions of chloride of sodium, and it is insoluble in a saturated solution of the same salt. The precipitated sulphate of lime is redissolved when the water cools down; but this process is the slower the higher the temperature at which it was precipitated. When the deposit is formed at 300° Fahr. it takes several days before it is redissolved by the water, even if the quantity is small relatively to the water.

The *chloride of calcium*, formed by a reaction between the carbonate of lime and the chloride of magnesium, is soluble in water, and undergoes no decomposition in the presence of water at the temperatures obtaining in steam boilers.

The *chloride of sodium*, or common salt, which forms by far the greatest proportion of the saline matter of sea-water, undergoes no decomposition by heat. Its solubility in water is nearly the same at all temperatures:

100 parts of water at 57° Fahr. dissolve 36 parts of this salt.
" " " 140° Fahr. " 37 " "
" " " 212° Fahr. " 40 " "

The *chloride of magnesium* is very soluble in water. At 60° Fahr. 100 parts of water dissolve 200 parts of this salt. It is decomposed at 212° Fahr., forming hydrochloric acid and magnesia; the latter substance is deposited in the form of a white powder, while the former enters into combinations with the iron of the boiler and with the lime. (*See sections* 7 *and* 11, *chapter* xviii.)

Sulphate of magnesia.—100 parts of water at 207° Fahr. dissolve 644 parts of the crystallized salt; 100 parts of water at 58° Fahr. dissolve 104 parts.

6. Composition of Boiler-scale.

Station.	Fracture.	Sulphate of lime.	Carbonate of magn.	Magnesia.	Water.
Hamburg......	Partly crystallized.	85.20	2.25	5.95	6.5
Mediterranean..	Amorphous.......	84.94	2.34	7.66	4.65

The water was present in mechanical combination. (*Engineering*, 1866.)

In the 'Third Report of the Admiralty Committee on Boilers' the composition of scale from the boilers of various ships is given—viz.:

	H. M. S. *Amethyst.*	H. M. S. *Malabar.*	H. M. S. *Fox.*	S. S. *Patroclus.*	S. S. *Velindra.*
Sulphate of lime	94.64	95.93	77.30	96.37	91.38
Magnesia...........	2.88	3.10	10.55	1.62	2.31
Silica	Traces.	0.40	Traces.	0.60	1.40
Peroxide of iron.....	Traces.		5.80		1.60
Water..............	2.45	....	6.00	1.75	3.30

In the boiler of the S. S. *Deccan* the water had been raised to ten times the density of sea-water, so that the brine contained in 100 parts—

Chloride of sodium	27.76
Chloride of magnesium	3.72
Sulphate of magnesia	1.65
Sulphate of potassa	0.87
Water	66.00

and had a specific gravity of 1.224 at 60° Fahr. The thick saline deposit from the furnace-crowns of this boiler contained in 100 parts—

Chloride of sodium	97.83
Chloride of magnesium	0.59
Sulphate of lime	0.56
Peroxide of iron	0.02
Water	1.00
	100.00

7. Cousté's Theory of the Formation of Deposits in Steam Boilers.—When sea-water in its natural state is evaporated in a boiler the following phenomena are observed:

I. A few moments after ebullition commences the water in the boiler grows turbid, and holds in suspension first free magnesia, then carbonate of magnesia. These two substances are present in small quantities, and are light, flaky, and have no tendency to agglomerate. They form with the organic and earthy substances which the water holds

in suspension the muddy deposits which are found in the bottom of boilers and on horizontal heating-surfaces.

II. By the continuance of ebullition the water arrives soon at the point of saturation with regard to the sulphate of lime, and from this moment, if the degree of saturation is allowed to pass the point where the motion of the molecules of water are capable of keeping the particles of sulphate of lime mechanically in suspension, these particles are deposited as a crystalline crust on all surfaces in contact with water.

III. The heating-surfaces impart to the water in contact with them a sufficiently high temperature to make it supersaturated as far as the sulphate of lime which it contains is concerned. This sulphate is then deposited on the plates constituting the heating-surfaces, forming there at once a thin layer of incrustation, whatever may be the degree of concentration of the mass of water. Afterwards, when the degree of concentration rises above the point mentioned above (see II.), the particles of sulphate of lime spoken of in the same paragraph cling to this layer and increase the thickness of the scale. It appears that in case those particles which are precipitated without being in contact with the heating-surfaces did not cling to such a layer of scale, they would not adhere to the metal of the heating-surfaces, and would form merely a deposit and not scale.

IV. When the fires are hauled and the water in the boiler has cooled down, that portion of the muddy deposit which the water held in suspension by the motion of its particles produced by ebullition falls down on the surfaces of the boiler, or rather on the scale which covers them. This extremely thin layer of mud, lodged in the depressions of the rough surface of the scale, remains there mostly when vaporization recommences. Then, as soon as the water reaches again the above-mentioned point of concentration, a second layer of sulphate of lime is formed on top of the first one, but separated from it by a film of magnesia and carbonate of magnesia combined with a little oxide of iron and organic matter which give a yellowish color to this film. Since the evaporation is very active on the crown-sheets of the furnaces, the incrustation forms there very rapidly; hence the scale should be much thicker there than elsewhere. But the contrary is the case, because as soon as scale is formed it is detached by the contractions and expansions of the metal occurring every time the intensity of the fire varies. Indeed, it is found that the scale which covers this portion of the heating-surfaces consists generally of a single layer, a fracture showing no intermediate film. For the contrary reason the scale reaches greater thickness at points of less intense heat, where it is composed of distinct layers separated by films, each layer being generally less thick than the single layer on the furnace-crown.

V. The fracture of the incrustations shows an amorphous structure throughout nearly their whole thickness, except at the side opposite to that in contact with the metal, where it has an appearance of crystallization. On the other hand, the greater part of the isolated concretions which are found at the bottom of the boiler consist each of an amorphous core enveloped by crystalline layers. These facts indicate that, at the moment when a layer is deposited, it has a crystalline character due to the presence of a certain proportion of water; but after having been in contact with the metal for a certain length of time, this water of crystallization is set free and the scale becomes amorphous. Contact with the heating-surfaces suffices to produce this effect, for their temperature exceeds always 570° Fahr., and it is known that 390° are sufficient to deprive the sulphate of lime of its water of crystallization. Besides, it is easily conceived that this calcination is less complete as the portions of scale are farther removed from the metal, and is nothing at the face in contact with the liquid. (*Ledieu.*)

8. Prevention of the Formation of Scale in Boilers.—Three methods are employed to prevent the accumulation of scale in marine boilers—viz. : I. Blowing-off a portion of the water in the boiler when it has reached a degree of concentration at which deposits would be formed, and replacing it by ordinary sea-water. II. Feeding the boiler with water from a surface-condenser or distilled by a special apparatus, or with sea-water which has been deprived of a portion of its salts by heating it to a high temperature in a separate vessel. III. Mixing various substances with the water of the boilers, which prevent the formation of scale either by mechanical or by chemical action. (*See section* 11, *chapter* xviii.)

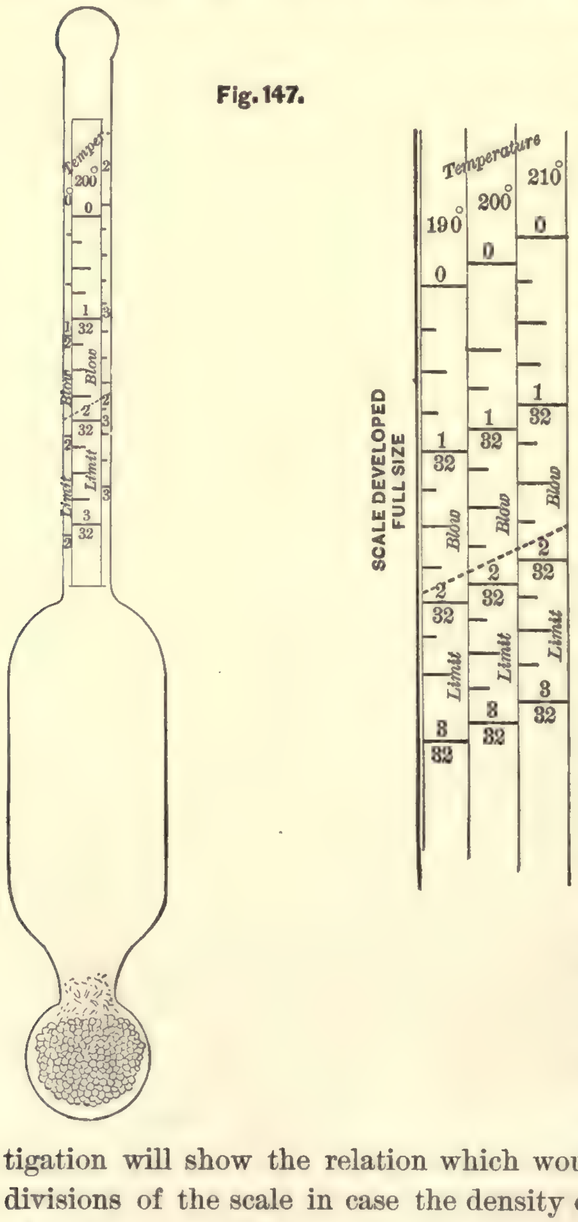
9. The Hydrometer.—The concentration of the water in the boiler is determined by means of an instrument called "*hydrometer*" or "*salinometer*," which is a float having a constant weight and measuring by the depth of its immersion the relative bulk of fluids of different densities having the same weight.

The hydrometer used in the United States Navy is a graduated narrow, cylindrical tube closed at the top. The lower part is enlarged to give buoyancy to the instrument, and terminates in a small globe filled with shot, which serves to keep the hydrometer floating in an upright position (see figure 147).

These instruments are generally made of glass, and the scale is marked on a slip of paper, which is secured within the narrow tube. Each vessel is also furnished with a standard copper hydrometer of similar shape, having the scale engraved on the narrow stem. It is necessary to handle these latter very carefully, since any indentation would alter the relation existing between the bulk and the weight of the instrument, and consequently destroy the correctness of the scale.

In order to graduate this instrument it is first placed into a vessel containing distilled water of a fixed temperature, and the point to which it is immersed is marked zero. Then sea-salt is dissolved in the water in the successive proportions of one, two, three pounds, etc., of salt to thirty-two pounds of water, and the respective points to which the instrument, floating in the solution, is immersed at a uniform temperature are marked $\frac{1}{32}$, $\frac{2}{32}$, $\frac{3}{32}$, etc. Each of these divisions is further subdivided into halves and quarters. The temperature for which the hydrometer is graduated must be marked on the scale. Hydrometers have sometimes three different scales, corresponding respectively to temperatures of 190°, 200°, and 210° Fahr.

Fig. 147.



Approximately, for an increase of 10° in temperature the density of the solution, as indicated by the hydrometer, decreases by one-eighth of a division—in other words, the hydrometer will indicate a concentration which is one-eighth of a thirty-second less than the true one when the temperature of the solution is 10° higher than the temperature for which the scale was constructed. It is, therefore, necessary to keep a thermometer immersed in the water which is drawn from the boiler into a suitable vessel for the purpose of testing its concentration. (*See section* 10, *chapter* xv.)

The divisions of the scale constructed in the aforesaid manner are not uniform, but decrease in length as the degree of concentration increases. The following investigation will show the relation which would exist between the lengths of successive divisions of the scale in case the density of the solution was proportionate to the sum of the densities of its separate constituents:

If $w =$ the weight of water contained in the solution,
$v =$ its corresponding volume,
$d =$ the volume of salt, the weight of which is $\frac{w}{32}$;

and if x, x_{1}, x_{11}, x_{111}, etc., represent the volumes of the solution displaced by the hydrometer at successive degrees of concentration corresponding to 0, $\frac{1}{32}$, $\frac{2}{32}$, $\frac{3}{32}$, etc., of the scale, then, since the weight of these volumes is equal, we have the equations:

$$\frac{w}{v} x = \frac{33\, w}{32\,(v + d)}\, x_{1} = \frac{34\, w}{32\,(v + 2\,d)}\, x_{11} = \frac{35\, w}{32\,(v + 3\,d)}\, x_{111}, \text{ etc.};$$

consequently

$$x_{1} = \frac{32\,(v + d)}{33\, v}\, x;\ x_{11} = \frac{32\,(v + 2\,d)}{34\, v}\, x;\ x_{111} = \frac{32\,(v + 3\,d)}{35\, v}\, x, \text{ etc.};$$

and the length of each division is proportionate to

$$x - x_{1} = x - \frac{32\,(v + d)}{33\, v}\, x = \frac{v - 32\, d}{33} \left(\frac{x}{v}\right);$$

$$x_{1} - x_{11} = \frac{32\,(v + d)}{33\, v}\, x - \frac{32\,(v + 2\,d)}{34\, v}\, x = \frac{32}{33} \cdot \frac{v - 32\, d}{34} \left(\frac{x}{v}\right);$$

$$x_{11} - x_{111} = \frac{32\,(v + 2\,d)}{34\, v}\, x - \frac{32\,(v + 3\,d)}{35\, v}\, x = \frac{32}{34} \cdot \frac{v - 32\, d}{35} \left(\frac{x}{v}\right), \text{ etc.}$$

The density of the brine, however, does not increase proportionately with the weight of salt held in solution, but a condensation takes place when salt is dissolved in water, which appears to be greatest for very much diluted brines; when 100 ounces of water are mixed with 34 ounces of common salt the decrease in volume is equal to 4 per cent. of the sum of their respective volumes.

The presence of saline matter in water has the effect of raising its boiling point, and this property has been made use of to determine the concentration of the solution. For water containing the usual proportions of the salts of sea-water the boiling temperature under mean atmospheric pressure is raised very nearly one degree for each additional 2.58 per cent. of saline matter.

The specific heat of sea-water is .82, that of fresh water being 1.00.

10. Influence of Temperature and Pressure on the Limit of the Saturation of Water in a Boiler.—The hydrometer indicates the density of the water in the boiler due to the saline matter held in solution, but gives no indication of the relative quantities of the different salts constituting this saline matter. The formation of scale depends chiefly on the quantity of sulphate of lime present in the water, and this salt will be deposited when the temperature reaches a certain point, whatever the con-

centration of the water, as indicated by the hydrometer, may be. By reference to Table XXXVIII. it will be seen that when the temperature of the water becomes 264° it can no longer hold the whole quantity of sulphate of lime present in ordinary sea-water, and when the temperature rises to 280° it cannot hold any of this salt in solution. Under these circumstances the amount of deposit formed is in the direct ratio of the quantity of this salt introduced into the boiler with the feed-water; and since blowing-off necessitates an increase in the quantity of feed-water, it increases instead of diminishing the formation of a deposit of sulphate of lime and magnesia, besides wasting the heat imparted to the water which is blown off, and introducing additional quantities of air and of the destructive chloride of magnesium into the boiler. The only advantageous effect of blowing-off under these conditions is the removal of the particles of lime and magnesia kept in suspension mechanically by the currents of water in the boiler.

Supposing that by feeding from the sea the concentration of the water in the boiler is raised to $\frac{2}{32}$ on the scale of the hydrometer, and when this point is reached the sea-feed is shut off and the supply of distilled water from the surface-condenser is substituted, no more lime-salts will be introduced and no more scale will be deposited, but the hydrometer will still indicate $\frac{2}{32}$.

TABLE XXXVIII.

Absolute pressures in atmospheres.	Temperatures of steam, corresponding to pressures, in degrees Fahr.	Density of water at a temperature of 59° Fahr.	Weight of sulphate of lime contained in 100 parts of the water in the boiler.	Total weight of saline matter contained in 100 parts of the water in boiler.	Degrees of concentration indicated by hydrometer.	Temperatures at which the water would boil under mean atmospheric pressure.
1.00	212	1.0990	0.6000	13.979	$5\frac{1}{4}$	216.32
1.25	224	1.0768	0.4683	10.912	$3\frac{7}{8}$	215.42
1.50	234	1.0589	0.3834	8.935	$3\frac{1}{8}$	214.52
1.75	243	1.0459	0.3055	7.120	$2\frac{1}{2}$	214.16
2.00	251	1.0344	0.2335	5.442	$1\frac{7}{8}$	213.62
2.25	258	1.0245	0.1688	3.934	$1\frac{3}{8}$	213.39
2.50	264	1.0162	0.1132	2.639	$\frac{7}{8}$	213.35
2.75	270	1.0078	0.0551	1.285	$\frac{1}{2}$	213.34
3.00	275	1.0002	0.0012	0.030	$\frac{1}{8}$	213.33
3.25	280	the water cannot hold any portion of sulphate of lime in solution.				
3.50	285					

The foregoing table contains the conditions accompanying the saturation of sea-water with regard to the sulphate of lime at various pressures and temperatures. The data, adapted to our hydrometric scale and to Fahrenheit's thermometric scale, are selected from a table prepared by Cousté. It is based on the assumption that sea-water

in its natural state, and having a density of 1.026, contains 0.15 per cent. of sulphate of lime, 2.65 per cent. of chloride of sodium, and 0.70 per cent. of other substances, or in all 3.50 per cent. of saline matter and 96.50 per cent. of fresh water.

11. Calculation of the Quantities of Water and Heat lost by Blowing-off.—In order to maintain the water in the boiler at a certain concentration the quantity of water extracted by blowing must bear to the quantity of water fed into the boiler the same ratio as the number indicating the concentration of the feed-water to the number indicating the concentration of the water in the boiler.

Let x represent the number on the hydrometer indicating the density of the feed-water;
" y " the number on the hydrometer indicating the density of the water in the boiler;
" s " the number of pounds of water evaporated in a unit of time;
" b " the number of pounds of water in the brine which is blown off.

Supposing the quantity of water in the boiler to remain the same, then the quantity of salt blown off in a unit of time must be equal to the quantity of salt introduced with the feed-water in a unit of time, in order to maintain the concentration at a fixed point. This relation may be expressed by the following equation:

$$x\,(s + b) = y\,b; \text{ hence } (s + b) : b :: y : x,$$

which proves the above rule.

In calculating the loss of heat by blowing-off absolute accuracy cannot be attained, because the specific heat of sea-water at different densities has not been ascertained. It has been taken as being the same for all densities as ordinary sea-water—viz., 0.82—although for greater densities it is probably smaller. Further, since the boiling-point of sea-water at different concentrations has not been ascertained for pressures higher than the atmospheric pressure, no account has been taken in the following example of any increase of temperature due to the higher degree of concentration. For simplicity's sake the temperature of the water may be taken as representing the units of heat contained in each unit of weight. The error due to these causes is slight and practically unimportant. The method of calculating the loss of heat by blowing-off will be explained by the following example:

Supposing the temperature of the feed-water to be 110°, its concentration $\frac{1}{32}$ on the scale of the hydrometer, the steam-pressure in the boiler 35 lbs. per square inch above the atmosphere, what percentage of the total heat imparted to the water in the boiler is lost by blowing-off when the density of the water is kept at $\frac{1.75}{32}$ on the scale of the hydrometer?

Regarding the weight of water evaporated as unity, the weight of fresh water contained in the brine blown off, represented by b, bears to the weight of fresh water contained in the feed the following proportion—viz.: $b : (1 + b) :: 1 : 1.75$; hence $b = \frac{1}{.75} = 1.333$.

The total weight of brine blown off is consequently $= 1.333 + \frac{1.333 \times 1.75}{32} = 1.406$; and the total weight of feed-water for each pound of water evaporated $= 2.406$.

The temperature of steam at a pressure of 35 lbs. above the atmosphere is 280° in round numbers. The units of heat present in the feed required for each pound of water evaporated are $(2.406 \times 110 \times .82) = 217.02$.

The units of heat required to raise the amount of water blown off from 110° to 280° are equal to $1.406 \times (280 - 110)\ .82 = 196.00$.

Total units of heat present in each pound of steam	= 1199.4
" " " " in water blown off = (1.406 × 280 × .82) =	322.8
Total units of heat in water and steam	= 1522.2
" " " present in feed-water	= 217.0
Total units of heat communicated to the water	= 1305.2

Percentage of heat in water blown off in terms of total heat expended $= \frac{196 \times 100}{1305.2} = 14.94$ per cent.

12. Cleaning and Scaling Boilers.—The boilers should be cleaned of soot and ashes as soon as possible after the fires are hauled. The tubes are to be swept first, commencing with the top row of each tube-box. Before commencing to sweep the tubes turn the ventilators away from the wind and close the furnace and ashpit doors, so that as little dust as possible may fly about the fire-room; but open all the connection-doors to let the draught carry the soot or ashes up the chimney.

Tube-brushes are made either of wire or of coir. They should fit the tubes snugly so that it requires some force to push them through, because they should not merely remove the loose soot, but detach also the hard carbonaceous scale which covers the fire-surfaces of the tubes. This scale frequently clings so tenaciously to the surfaces that it has to be scraped off.

Tube-scrapers consist of steel strips secured to circular end-pieces and bent so as to form ridges running at an angle with the axis of the tool. An efficient scraper is formed

by long, thin steel strips bent to a spiral shape, which are secured to short, cylindrical end-pieces, and can be adjusted to a greater or less diameter by moving a nut in the direction of the axis of the tool.

Deposits of salt from leaks which may have accumulated in or around the tubes must be carefully removed with a scraper or long chisel. In the narrow spaces between vertical water-tubes such deposits are frequently very difficult to remove, unless they are loosened by soaking them for a long time in fresh water. For this purpose a dam is built up at both ends of the tube-box, and water is kept in the latter at such a height as to cover the deposits of salt. Such deposits may also be loosened by directing against them, by means of a hose, a strong stream of water thrown by a force-pump. But in no case should water be used in the flues or connections unless the tubes, connections, and furnaces have been thoroughly cleaned of soot and ashes.

After the tubes have been cleaned remove the soot from the uptake and back-connections; scrape the plates clean of scale and salt, and sweep them off with a stiff broom. The furnaces and ashpits are to be cleaned in the same manner after the grate-bars have been removed. The grate-bars are to be cleaned by knocking clinkers and cinders off with a scaling-hammer. Cast-iron bars which are much broken, burnt, or bent have to be replaced with new ones; wrought-iron bars have to be repaired or straightened.

The chimney is to be swept and scaled periodically on the inside. When bituminous coal is burnt the accumulation of soot in the chimney becomes so great that it frequently catches fire and causes serious injury to the chimney unless it is swept off periodically.

The outside of boilers must be cleaned of salt deposited from leaks after every run. When the leak cannot be repaired before the boilers are put in use again the deposits which close a leak should not be disturbed. Special attention must be paid to the cleaning of the front of boilers, where salt accumulates in consequence of the water leaking from the water-gauges. The lower part of the boiler-front is generally covered by a coating of ashes, which cling to the boiler when they are wetted after hauling them from the furnaces and ashpans. The bottom of boilers is frequently found covered with salt and dirt deposited by the bilge-water which is washed up against the boiler by the rolling of the vessel. Dry ashes and dust accumulate on the top of boilers, and must be swept off from time to time.

The water-gauges, salinometer-pots and their pipes, and other attachments must be cleaned not only on the outside, but must be disconnected so as to clear their passages of scale and sediment. Valves and cocks must be reground and packed, if necessary.

Valve-stems and plug-cocks must be greased with oil or tallow, and the articulations of safety-valve levers must be cleaned and oiled.

The outside of boilers must always be kept covered with a heavy coat of paint, which will require frequent renewal at the front and bottom, where the leakage of water from the gauges and the manholes and mudholes, the wetting of ashes, and the washing-up of the bilge-water render the boiler especially liable to corrosion, while the frequent cleaning and scraping soon wears off the coat of paint. For painting the shell of boilers either red lead or a brown metallic paint prepared from the brown oxide of iron is used. The furnaces, connections, uptakes, and the inside of chimneys should receive a coat of the same paint when the boilers are to be put out of use for some time. The inside of steam-drums, if accessible, should be kept covered with a heavy coat of lead or brown metallic paint, especially the lower part of horizontal drums, where water is apt to collect. The cast-iron of connection, furnace, and ash-pit doors may be painted with lamp-black and oil, or may be simply oiled. Some engineers paint the connection-doors white, in order to make the fire-room brighter. In no case should the iron of boilers be whitewashed, unless it has first received a heavy coat of paint, because the lime absorbs moisture, and thus would promote corrosion. The outside of chimneys, the hatch-gratings, ventilators, etc., may be painted with asphaltum. In no case should paint be applied to any part of the boiler before it is thoroughly dried, cleaned, and scaled, so that the paint may cover the clean body of the metal.

The scaling of boilers should be commenced as soon as they have cooled off sufficiently to be entered, for when the scale is still damp it can frequently be removed much more easily than after it has got quite dry. As long as the thickness of the scale does not exceed the thickness of ordinary writing-paper it should not be disturbed, as it forms the best protection of the iron against corrosion; but as it grows thicker its low thermal conductivity produces a perceptible diminution of the evaporative efficiency of the boiler, and exposes the plates to the danger of being burnt. The expansion and contraction of the plates cause thick scale to crack and to become partially detached from the plates, and in this condition the scale favors the corrosion of boilers by admitting and retaining moisture in contact with the plates.

It has been recommended to loosen the scale, before commencing the operation of cleaning the boiler, by the sudden expansion or contraction of the plates or tubes. This might be done by admitting cold water into the boiler immediately after hauling the fires and blowing the hot water out of the boiler; or by admitting a large mass of steam into the cooled-off boiler and allowing it to condense there; or by making a light fire of

wood-shavings in the furnaces or connections. The latter plan has resulted in several instances in burning the boiler. But all these methods should be avoided, as the sudden expansion and contraction of the plates is always injurious to the boiler.

The scale on the plates must be chipped off with scaling-hammers or wedged off with scaling-bars. These tools must not be ground to a sharp edge, and the chipping must be done carefully to avoid making indentations in the surface of the iron and injuring the rivet-heads; where such indentations are made the scale which is subsequently formed adheres more tenaciously, and the iron is more readily attacked by corrosion. Special care must be taken in scaling the tube-sheets to avoid injuring the tube-ends. The crown-sheets of furnaces are generally scaled first. The scale should be removed completely from the plates wherever they are accessible, especially between the rivet-heads and at the edges of laps, and around the crow-feet or the heels of braces. The narrow water-spaces around the back-connections are frequently not accessible for thorough scaling unless handholes are cut at suitable places in the shell.

The fire-tubes of marine boilers are generally spaced so closely that the greater portion of their surfaces is not accessible for scaling. The vertical spaces between these tubes must be kept clear by running a scaling-bar through them, by which means the scale may be detached from the tubes in flakes. Various devices for making the tubes readily removable for scaling have been tried, but have not given satisfactory results. When the accumulation of scale on the tubes becomes very great it will be necessary to remove a sufficient number of tubes from the boiler to make the remaining ones accessible for scaling.

Water-tubes can be scaled by running through them a steel bar with a cutting edge at the end, or by boring out the scale with *Garvin's scaling-tool*, consisting of a revolving cutter worked by a wrench, and fed by turning a screw which passes through the tube and is secured and centred at both ends. Care is required in working and adjusting these tools so as not to cut into the metal of the tube.

The shell of the boiler in the water and steam spaces must be scraped clean of mud and rust, all the loose scale must be knocked off the braces, and the whole mass of scale and dirt must be swept down through the water-spaces to the bottom of the boiler, taking special care that no dirt lodges between the tubes or on the furnace-crowns. The dirt is then raked with small hoes out of the boiler through the mudholes in the bottom.

Finally the boiler is to be washed out. By means of a hose, connected to a force-pump, direct a heavy stream of water at every portion of the interior of the boiler, especially at such parts as are not accessible for scraping. By this means much loose

scale and mud will be washed down. The latter contains frequently grease, partly decomposed, various salts, particles of copper, and other substances which are very injurious to the boiler. Commence the washing-out in the steam-space, directing the jet of water especially into the steam-drum, between the tubes, and into the water-spaces around the back-connections. Then take the hose in succession into each manhole over the furnace-crowns, and finally into the mudholes at the bottom; commencing at one end of the boiler, wash all the dirt to the other end. During this operation continue to rake the dirt and scale out through the mudholes in the bottom. Give a slight list to the vessel while washing out the boilers, so that the water will naturally flow to the front of the boilers, carrying the dirt along with it. The fire-room floor-plates in front of the boiler are removed to let the water run directly into the bilge of the vessel.

After the boiler has been washed out, and all the water removed from the bottom by raking and swabbing, the boiler must be kept open till it is perfectly dry in every part. Pans with burning charcoal may be placed in the furnaces and connections to dry the boiler more rapidly. (*See section* 14 *of the present chapter.*)

13. Repairing Boilers.—All leaks, however small, should be stopped as soon as possible, and all temporary repairs, such as have been described in section 3 of the present chapter, should be replaced, after the boilers are emptied, by substantial work which will correct the evil permanently and strengthen the defective part. The mass of steam evolved from a leak frequently prevents its exact location while the boiler is under steam, and the accumulation of salt deposited by the water issuing from a leak is often so great that its source cannot be traced after the boiler is emptied, except by filling it again with cold water and producing a pressure in it by means of a force-pump.

Leaky seams and rivets must be calked. When a rivet leaks after repeated calking it must be cut out and a new rivet put in its place. The same must be done with rivets the heads of which are so much corroded that their holding power is seriously impaired. Such rivet-heads are found especially at the bottom of boilers on the outside of the shell and in the connections and uptakes, and their condition is frequently not indicated by any leaks, and may not be discovered, since the corroded heads often retain their original shape, unless they are tested by striking them with a hammer. In places where new rivets cannot be driven properly bolts secured by nuts may be substituted for them. To make a tight joint with them wrap a little hemp or cotton wick covered with putty around their shank close under the head, and put a washer covered with stiff putty under the nut. Such bolts must likewise be used when the boiler is old and weak, as the jars produced by riveting and calking would be likely to start new leaks.

These bolts have frequently to be *wired* in place by the same method as is applied to sockets, described in section 3, chapter x.

In replacing a socket-bolt keep the socket in place by inserting the new bolt or a temporary plug as the old bolt or rivet is being withdrawn. After removing screw stay-bolts the threads in the plates are generally found so much injured that the holes have to be reamed out and new threads cut, necessitating the use of larger bolts. When the holes have become much enlarged or the plates much weakened by corrosion replace socket-rivets and screw stay-bolts with socket-bolts, and put large washers under their heads and nuts.

Defective parts of a boiler have often to be patched with plate-iron, in order to strengthen them or to stop leaks.

When a patch is riveted on and made tight by calking it is called a *hard* patch. When a patch is bolted over the defective place, the joint being made with putty, it is called a *soft* patch. The bolts are generally secured by nuts, but sometimes tap-bolts have to be used. The putty is prepared by kneading together white lead, ground in oil, with dry red lead, and mixing with it some fine iron borings or filings to make it stiff.

A soft patch should not be applied to a surface in contact with fire or hot gases, except in case of necessity as a temporary expedient to stop a bad leak. When a soft patch has been applied to a furnace-crown it is best not to use the furnace, because the heat would cause the patch to warp sooner or later. On the bridge-wall or on the bottom of the back-connection a soft patch may be protected by covering it with fire-clay or ashes. When a boiler is old and weak a soft patch is often to be preferred to a hard patch to avoid jarring the boiler by riveting and calking. Leaky seams which have been repeatedly calked, so that the lap is much reduced in width, have to be made tight by covering them with a soft patch. It must be observed that a soft patch generally does not add to the strength of the defective plate, but is frequently the cause of greater weakness on account of the metal cut away in drilling the bolt-holes, and because corrosion may continue unseen under the patch.

When a hard patch is to be applied to the outer shell it may be placed directly over the defective plate. But in places which come in contact with the fire or hot gases it is necessary to reduce the thickness of the metal as much as possible; therefore the defective part has to be cut out. The hole thus formed in the plate should be rounded, since sharp corners favor the formation of cracks.

Cut the patch from boiler-plate of good quality and of the same thickness as the plate which is to be repaired, unless the latter is much worn, when the patch may be reduced in thickness. It is advisable to calk the edges of the patch rather than those of

the old plate; for this reason, in repairing a crown-sheet, put the patch inside the furnace; in this position it can also be fitted better than when it is placed inside the boiler. After cutting away the defective portion of the plate with a cape-chisel, lay off and drill around the opening rivet-holes of the required size and spaced according to the rules given in sections 13 and 14, chapter viii. Fit the patch so that it lies close on the plate, and, holding it in position, mark on it the rivet-holes and the opening cut in the plate. Then drill the holes and trim the patch to the proper size and form. Bolt it securely in place while it is being riveted, and finally calk it.

When the patch is to cover a curved or uneven surface make a template for it of a piece of sheet-lead hammered into shape while holding it against the surface to be covered. After fitting and drilling the patch heat it to a dull-red heat, put it in position, and draw it tight up against the plate by means of bolts, so as to make a close fit.

Blisters occur frequently in iron plates exposed to an intense heat. When they are thin it is sufficient to chip them off as far as the lamination extends; but when a blister is thick the plate has to be cut out and patched. Some engineers recommend to rivet blisters down when they first appear, and thus prevent their extension.

Cracks formed by unequal expansion in the middle of plates, or starting from rivet-holes, are sure to increase in length unless promptly stopped. When a crack does not exceed three inches in length it may be closed with rivets. Drill a small hole at each end of the crack, taking care that it does not extend beyond the holes, then drill one or two more holes through the crack and countersink them. Put rivets through these holes and spread their heads well, hammering them down pretty flat so that they cover the crack completely.

When the crack is of considerable length the corresponding portion of the plate must be cut away and patched. The same must be done when cracks run from hole to hole in a seam, or when a number of cracks appear in close vicinity, running from the rivet-holes of a seam to the edge of the plate.

When a furnace-crown has *come down*, or partly collapsed, but the injury is not very extensive, it may be restored to its original shape. Bring the defective place to a dull-red heat by means of a charcoal-fire in a portable furnace, then force it up with a screw-jack, placed on a foundation of blocks in the ashpit, and acting directly on a block the upper surface of which has the shape of the furnace-crown. The adjoining uninjured parts of the crown-sheet should be firmly wedged to prevent their distortion during this operation. It is to be observed that the injured part never regains its original strength and stiffness. It may be strengthened by additional braces, or by angle-iron rings, as described in section 6, chapter ix. The safest plan is to renew the plate, either

in part or wholly, according to the extent of the injury. When these precautions cannot be taken before the boiler has to be used again, the defective furnace may be put out of use and the injured crown-sheet shored up.

When a crown-sheet is defective in several places it is better to cut out the whole plate, or at least the portion containing the several defects, than to put on a number of small patches. Arrange the patches so that their seams do not come close to the fire, and that they clear the crow-feet and other attachments of the braces.

When tubes leak in the joints at their ends, and cannot be made tight by expanding or calking them, the leak may be stopped by driving ferrules in their ends. Several methods of plugging fire-tubes have been described in section 3 of the present chapter. On account of the expansion of the rod exposed to the hot gases, water-tubes cannot be plugged effectually in the same manner as fire-tubes by passing through them a long rod with a nut at each end which holds the cup-washers that cover the ends of the tube. Such tubes must be cut out, and the holes in the tube-sheets must be closed by cup-washers, each held by a short bolt having a T-head or passing through an iron bar which straddles the tube-hole. Tubes which have been plugged should be replaced as soon as possible with new ones. The manner of securing tubes has been described in section 6, chapter xi.

To remove a ferrule from a tube split it by cutting a groove through it with a cape-chisel. A tube in one of the outside rows may be removed by cutting it off with a tube-cutter or with a chisel inside the tube-sheets. To remove a tube from one of the inner rows bend its ends inward, pass a rod through it, and put a nut and washer at one end; hook a tackle at the other end and pull the tube out, driving it at the same time at the other end. The accumulation of scale on a tube makes its passage through the hole in the tube-plate often very difficult. The scale may be cracked off by inserting a red-hot iron bar into the tube. Tubes which have been removed can often be used again in shorter boilers after cutting off their battered ends, or they may be lengthened by brazing new ends to them.

If a tube-plate is bulged from any cause, tie it to the opposite tube-plate by means of rod-braces which take the place of some of the tubes, and are held at the ends by nuts and stout washers, or substitute stay-tubes secured by nuts for a number of tubes expanded in the ordinary manner.

Leaky seams of old boilers which cannot be calked properly may be made tight by driving an iron cement into them, forming a rust-joint. The following composition for such a cement is given by Roper: cast-iron borings or turnings, 19 lbs.; pulverized sal-ammoniac, 1 lb.; flour of sulphur, $\frac{1}{2}$ lb.; should be thoroughly mixed and passed

through a tolerably fine sieve. Sufficient water should be added to wet the mixture through. It should be prepared some hours before being used. A small quantity of sludge from the trough of a grindstone will improve its quality. Instead of sal-ammoniac, urine may be used.

When a boiler is old and much worn leaks in seams, around rivet and stay-bolt heads, and at the ends of tubes frequently become very general. When time is wanting to subject the boiler to thorough repairs the leaks may frequently be stopped temporarily by introducing into the boiler oatmeal, or some other substance which is changed into a paste by boiling, and, after steam is formed, finds its way into every crevice or point of least resistance. The presence of such substances in the boiler produces, however, generally violent foaming, and they often obstruct the passages of water-gauges and clog the valve-seats.

When the water-legs and bottoms of old boilers are worn out generally, so that they can no longer be made tight by calking and patching, they may be filled with cement. Level the boiler by trimming ship till a little water in the boiler stands at the same depth everywhere. Close the mudhole-doors. Prepare a mixture of three parts of Portland cement and one of sand, or equal parts of Roman cement and sand, with water, thin enough to run, in a trough placed in the fire-room at a height slightly above the manholes between the crown-sheets. An inclined shoot leads from this trough to each manhole. The cement must be mixed in the trough in sufficient quantity at once and with some quickness, as it sets rapidly under water. The level of the cement in the boiler must be kept some inches below the grate-bars, and the extremities of the feed and blow pipes must be kept clear.

14. Preservation of Boilers.—A proper observance of the rules for the management of boilers given in the present chapter is essential for their preservation. The action of the various causes tending to deteriorate steam boilers, and the means by which their influences may be neutralized, will be described in detail in the following chapter.

The most efficient method of protecting a boiler against internal corrosion consists in covering its surfaces with a thin, adhesive layer of ordinary boiler-scale. This scale must be formed as soon as possible after steam is raised, before oxidation has commenced on the iron surfaces; and it must be very thin, otherwise it will soon crack with the expansions and contractions of the plates, and the moisture entering and retained between the iron and the scale will aggravate the evil of corrosion. It is recommended to keep the water in the boiler at about *three times* the density of ordinary sea-water for a short time after steam is raised, in order to produce this protective layer of scale.

In England a thin coating of Portland cement has sometimes been substituted for scale on the interior surfaces of boilers. It is recommended that all boilers under construction should receive such a coating, which should be renewed after the boiler has been tried under steam. The cement is ground very fine, and two parts of cement are mixed with one part of sand. Before applying it the iron should be scraped quite bare, otherwise the cement will not adhere to it. It is then applied with a common whitewash-brush like paint; as soon as one coat is dry another is laid on, two or three coats being applied in this manner. The cement becomes quite hard, almost like iron; the thinner it is applied the better, otherwise the expansion and contraction of the plates will throw it off. In some cases it has been found to stick upon the sides and tops of furnaces for two or three voyages. It is recommended to fill with it the holes caused by pitting, after scraping the respective parts quite clean. It is sometimes used as a foundation upon which a firmly-adhering layer of ordinary scale is allowed to accumulate. When it is properly applied it is not washed off by the feed, but on the *Sultan* and *Glatton* its use was discontinued because particles of it were carried over into the engines; this is ascribed to the faulty manner in which it was applied. Sometimes a layer of cement about 1 inch thick is applied to the bottom of cylindrical boilers inside to protect them against corrosion.

To prevent the corrosion of boilers when not in use they must be kept dry, and the iron must be covered inside and outside with a protective coating. Every part of the boiler should receive, when new, one or two coats of metallic paint. Boilers that are to be laid up for some length of time receive often inside a coat of oil, which is applied with a syringe at parts which cannot be reached with a brush. Fish-oil was formerly frequently used for United States naval boilers, but its use is now interdicted and hydrocarbon oils are to be used instead, because their decomposition is not accompanied by the formation of fatty acids. Boilers built for the English naval service have been completely filled with linseed or mineral oil. A pressure of 15 or 20 pounds was produced by means of a force-pump, provision being made for the escape of air from the upper corners of the boiler; the oil was then run out, and the process was renewed every six months. In other cases the boilers have been heated gently to dry them, and two coats of boiled linseed-oil have been applied. In all such cases the surfaces must be carefully cleaned of rust and loose scale before the oil is applied to them.

In the English navy two different systems are used for the preservation of boilers not in use. The one is known as the wet and the other as the dry system. The former consists in keeping the boilers filled completely with sea-water mixed with carbonate of soda; 25 pounds if soda-ash, or 50 pounds if ordinary crystal-soda, be used for every

100 cubic feet of sea-water in the boiler. This is to be dissolved and placed in the bottom before running up the boiler. The sufficient saturation of the water with soda should be tested by placing a piece of clean, new iron with some of the mixture in a bottle for a night; if the iron rusts more soda must be added. Special care must be taken that every part of the boiler is filled, the air being allowed to escape from the highest part of the boiler.

Instead of soda, slaked lime is also used, in the proportion of 8 pounds of lime to every 1,000 gallons of sea-water. This lime must be carefully cleaned out before getting up steam, or there may be heavy priming.

The dry process consists in removing all water from the boilers to dryness, by means of stoves if necessary; after which shallow iron pans containing altogether two or three hundred-weight of quicklime are placed in the bottoms, over the furnaces, and above the tubes, the quantity of lime depending on the size of the boiler. In addition a sheet-iron tray of burning coal is to be placed in the ashpits or furnaces till the coal is coked; then it is introduced into the boiler and the latter immediately closed air-tight. The burning coke consumes much of the oxygen of the air in the boiler, and increases the efficiency of the dry lime. At least every six months the boiler is to be opened for inspection, and, if the lime is found to be much slaked, the pans at the bottom, which can be removed without considerably changing the air, are to be taken out and refilled with fresh lime. In addition to this, when the atmospheric dampness is extreme, light fires in the ashpits are sometimes found to be necessary.

Weston found that the amount of oxygen lost by the air in boilers where the dry process had been used varied from nothing (in two cases) to 90 per cent. The dry-lime process frequently fails from the extreme difficulty of absolutely excluding moisture. By introducing the burning coke into the boiler 60 per cent. of the oxygen in the boiler may be consumed at once. After opening a boiler which has been treated by the dry-lime process, air must be allowed to circulate through it before any one enters it.

15. Extract from "Instructions for the Care and Preservation of the Steam-machinery of United States Naval Vessels (1879)."

"16. A thin deposit of scale will be useful in protecting the interior surfaces of boilers from corrosive action, and the use of zinc in the boilers will, it is believed, divert corrosion from the iron. In order that the best results may be obtained it is deemed advisable to ensure metallic continuity between the zinc and the boilers.

"17. No tallow or oil of vegetable or animal origin is to be put into the boilers for any purpose whatever, but *Crane's mineral oil*, or its equivalent, will be used. This

prohibition applies to all boilers in use in the navy under cognizance of this Bureau, of whatever type or service.

"18. The dry-pipes and drains of the steam-drums are to be examined frequently to ascertain if the holes in them are clear.

"19. The boilers, when empty, are to be kept dry by such means as are at the disposal of the officer in charge. The water-bottoms and lower parts of the fronts are to be kept free from scale, rust, and ashes, and well painted.

"20. The boilers are not to be used as water-tanks for fresh water, nor for trimming ship.

"21. The exteriors are to be kept as dry as possible, and nothing wet or combustible is to be stowed over or around them. The bilges in the fire-room are to be kept dry and well whitewashed.

"22. Sudden changes of temperature in the boilers are to be avoided, and, when time will permit, at least three hours should be occupied in raising steam from cold water.

"23. When not under steam a cover must be fitted to prevent water from going down the smoke-pipe.

"24. The uptakes are to be kept free from dirt and well painted.

"25. The number of hours each boiler has had fires within it since the ship was commissioned is to be stated in each quarterly report.

"26. After the fires are hauled, and before the water is blown out of the boilers, the furnaces and ashpits should be closed.

"27. The mineral oils which are to be used for interior lubrication float on the surface of the water in the boilers without being decomposed, and the surface-blows are to be used as rarely as possible, in order that the oil may not be blown overboard."

CHAPTER XVIII.

CAUSES AND PREVENTION OF THE DETERIORATION OF BOILERS.

1. General Causes of the Deterioration of Boilers.—The deterioration of boilers consists in the accumulation of calcareous scale and sediment within them, and in the diminution of their strength and the starting of leaks in consequence of corrosion and fracture and of the burning and distortion of the plates.

The deterioration of boilers is due to a variety of known causes, many of which are in a great measure avoidable, while for some of them no reliable practicable method of prevention has yet been discovered. There are some destructive agencies at work, shortening the life of boilers, the action of which is not fully understood ; and instances of rapid deterioration of boilers occur from time to time for which no definite cause can be assigned. In general the untimely deterioration of boilers may be traced to some of the following causes—viz. :

Inferior quality of or defects in the materials used in the construction of the boilers, especially the want of strength and ductility, and the presence of cracks, laminations, and surface-defects in plates.

Bad workmanship, causing injuries to the materials by punching, drifting, and burning, indenting the plates in calking, defective welding and riveting, and want of tightness in seams.

Deficiency of structural strength of the boiler and improper methods of connecting the various parts, causing severe local strains to be produced by the steam-pressure or by the unequal expansion and contraction of certain parts in consequence of variations of temperature.

Faulty design of the boiler, causing inaccessibility for cleaning and repairs, and defective circulation of the water preventing the free escape of steam from heating-surfaces.

Mismanagement of the boiler: subjecting it to great differences and sudden variations of temperature ; overheating the parts exposed to the direct action of the fire or hot gases ; letting the steam-pressure exceed the safe limit ; allowing the formation of thick deposits of scale, and neglecting to clean and repair the boiler in time, to keep it dry, to protect the surfaces by paint, etc.

The use of sulphurous fuel and of impure feed-water containing corrosive substances and producing deposits of solid matter.

Galvanic action in consequence of the presence of heterogeneous metals in the boiler, which either enter in its construction or have been introduced with the feed-water.

A gradual deterioration of boilers after they have been put in use appears unavoidable; but while stationary boilers frequently last twenty years, the life of marine boilers ranges, under favorable conditions, from nine to twelve years, and in naval vessels is often limited to six years of use.

The greater durability of stationary boilers compared with that of marine boilers is mainly owing to two circumstances. In the first place, stationary boilers can generally be made of such a size and capacity that there is no need of urging the fires, and of such a form that they are accessible in every part, that the circulation of the water and the escape of the steam from their heating-surfaces is unobstructed, and that the alterations of form due to variations of pressure and temperature do not produce severe local strains; while in marine boilers these conditions have frequently to be sacrificed on account of the restrictions with regard to weight and space imposed upon the designer. In the second place, the feed-water of stationary boilers is generally purer than that of marine boilers, since the water used for the purpose is either originally more free from injurious salts and acids, or can be passed through purifiers of ample capacity which would not be permissible on board of vessels on account of their bulk and weight.

A perceptible diminution of the endurance of marine boilers has taken place since the introduction of surface-condensers and of high steam-pressures.

The shorter life of boilers in naval vessels compared with that of boilers in merchant-vessels is to be ascribed principally to the irregular manner in which the former have often to be worked. The boilers of merchant-vessels are generally worked under uniform conditions for regular periods, with certain intervals of rest during which the boilers may be cleaned and repaired. On the other hand, in boilers of naval vessels steam has frequently to be raised very quickly. They are sometimes kept under steam for long periods, either working with full power or lying under banked fires; and at other times steam is raised and lowered, and the fires are started and hauled, after short intervals. Under these conditions the boilers of naval vessels are subjected to frequent changes and inequalities of temperature, and to frequent exposure of their imperfectly-dried surfaces to the action of the atmospheric air; their cleaning and repairs cannot take place at regular intervals, and the facilities for effecting thorough repairs are frequently wanting during long cruises on distant stations.

The formation of thick deposits of scale on the heating-surfaces of boilers not only

diminishes greatly their evaporative efficiency, but leads frequently to injuries affecting their strength and durability by causing the plates to become overheated. The conditions under which scale is formed, its character, and the method of preventing its formation by *blowing-off* have been discussed in sections 5–10, chapter xvii. Various other means of preventing its formation will be discussed in sections 10 and 11 of the present chapter.

The external corrosion of the shell of marine boilers—caused by leakage from seams, rivets, man and hand holes, water-gauges, etc., the leakage of water through the deck, and the action of the bilge-water and of wet ashes on the bottom and front of boilers—is easily prevented by stopping promptly all leaks, keeping the surfaces of the boiler clean, and protecting it with a coat of paint. (*See section* 12, *chapter* xvii.) The supports on which the boiler rests must be arranged in such a manner that the bottom of the boiler is easily accessible. External corrosion will also take place when boilers rest directly on oaken keelsons, or when copper bolts are allowed to come in contact with the iron of the shell of boilers. (*See section* 1, *chapter* xiv.)

The deterioration of the plates forming the heating-surfaces of boilers, produced by overheating, variations and differences of temperature, the corrosive action of the gases of combustion and of sulphuric acid distilled from soot, and the various causes of the internal corrosion of boilers, will be discussed separately in the following sections of the present chapter. Many of the causes of the deterioration of boilers may be prevented by observing the directions for the management of boilers given in chapter xvii. The internal corrosion of boilers is mainly due to the exposure of their damp surfaces to the atmospheric air, the presence of chloride of magnesium and of fatty acids in the feed-water, and the galvanic action of heterogeneous metals and especially of particles of copper, introduced with the feed-water, in contact with iron.

In some parts of the boiler the iron plates may be raised to a sufficiently high temperature to decompose the steam in contact with them, the oxygen combining with the iron and forming, according to circumstances, some one of the oxides of iron. There seems to be no doubt that this action frequently takes place in the uptake and in superheaters, in which places the corrosion of the iron plates generally presents a very different appearance from what it does at other parts of the boiler. Professor Hoffman concludes from direct experiments that the temperature of the iron has to exceed 356° Fahr. before decomposition of pure water takes place; and Professor Barff states that at a temperature of 650° Fahr. the black oxide of iron will be formed when iron is exposed to the action of superheated steam.

The question whether wrought-iron or steel is more liable to corrosion has to be con-

sidered as remaining undecided, the testimony in reference to this point being very conflicting. Steel plates having very nearly the same chemical composition, and exposed in the same boiler to apparently identical influences, have shown in some cases very different results as regards corrosion. It is, however, generally believed at the present day that the softer and purer kinds of steel and wrought-iron are more liable to corrosion than the harder and less pure ones.

Corrosion does not attack the surfaces of iron and steel plates in a uniform manner, and this fact is easily explained by the presence of structural differences in the plates. Wrought-iron and steel cannot have a perfectly homogeneous structure from the very nature of the processes of manufacture. The former is an aggregation of fibres welded together by squeezing, hammering, and rolling, or separated by thin layers of impurities; steel ingots are known to be traversed by innumerable air and gas cells, the walls of which are more or less perfectly welded together by hammering and rolling. A highly-polished plate of iron or steel exposed to atmospheric influences will show detached spots of rust at first, which gradually enlarge and spread over the whole surface. Powerful acids attack different parts of plates in a different degree, and thus develop their irregular structure.

In steam boilers, however, several other circumstances combine to make corrosive action very unequal. At places where the protective coating of the black oxide of iron or of adhesive scale has been detached and the clean iron is left exposed, and where the fibres of the metal have been loosened by bending, welding, etc., corrosion will commence and make the most rapid progress. Corrosive substances may be deposited on the plates in detached masses, and thus exert a powerful action.

Frequently the surfaces of plates exhibit detached cavities of small extent, but varying as to depth from a shallow depression to an actual perforation of the plate; sometimes only a few of these cavities lying far apart occur in a plate; at other times they lie so close together that the plate presents a honeycombed appearance. This phenomenon is called *pitting*. In the milder cases this form of corrosion may have been caused by surface-defects due to cinder-spots, etc., but it is probably more frequently produced by the intense local action of particles of corrosive substances, especially of fatty acids, or by the galvanic action of particles of heterogeneous metals.

When the plates exhibit deep furrows following well-defined directions the phenomenon is called *grooving*. These furrows are frequently found to run at a short distance from and parallel to seams, and their formation is explained by assuming that the repeated bending of the plates at these places in alternate directions has gradually detached the protective coating of scale and opened or broken the fibres of the metal,

and has thus facilitated corrosive action. Not unfrequently such a line of weakness is produced by cutting into the surface of the plate in chipping the edge of the lap for the purpose of calking it.

2. Deterioration caused by Overheating and by the corrosive Action of the Gases of Combustion.—Under the influence of the intense heat existing in the furnace and combustion-chamber the metal is liable to rapid oxidation, especially in laps and rivet-heads, where, in consequence of the greater thickness of metal, the difference of temperatures at the water and fire sides is relatively great. The metal is also liable to be destroyed by corrosive gases given off by the burning fuel. When sulphurous fuel is burned the plates exposed to a high temperature are acted upon with great rapidity, successive thin coats of bisulphuret of iron being formed on their surface.

In boilers worked with a strong artificial draught the cinders and fine particles of coal carried along by the blast gradually wear away the metallic surfaces against which they strike. This action has been observed especially in locomotives, where the front tube-sheet has been found to be much injured by it, and where the use of copper tubes had to be abandoned on that account.

The tubes and plates of superheaters located in the uptakes of boilers are liable to become overheated, especially in starting the fires before steam has formed; this may be prevented by filling them with water, which is to be drained off after steam has formed in the boiler. The upper part of the front of boilers in the uptake are exposed to the same injury. The rules of the Board of Trade (English) require that the flat ends of all boilers, as far as the steam-space extends, and the ends of superheaters should be fitted with shield or baffle plates where exposed to the hot gases in the uptake.

When parts of the boiler exposed to an intense heat—as the furnace-crown, the top of the back-connection and horizontal tubes—are left bared of water the metal soon attains a red heat. Iron tubes and plates collapse or bulge out and warp when they are overheated, and their strength is frequently permanently impaired; good, tough iron becomes brittle and weak when it is burnt. Brass loses its strength and disintegrates at a much lower temperature than that at which iron is injured. Horizontal fire-tubes of brass are quickly burnt when they are left bare of water, but in vertical tubes the water may be carried far below the upper tube-plate without injuring them.

The overheating of furnace-crowns and back-connections is frequently caused by the accumulation of scale or the formation of a saponaceous sediment. (*See section* 4 *of the present chapter.*)

Laminations existing in plates prevent the ready transmission of heat through them.

When such defects exist in plates forming the furnace or the combustion-chamber the layer in the plate nearest to the fire becomes greatly overheated, and, expanding, bulges out. When the extension of the metal has exceeded the limit of elasticity the metal does not resume its original shape after the heat has been discontinued, and a *blister* is formed, which increases in size with repeated applications of heat, and is sooner or later fractured, either at the apex when its thickness is uniform, or near the edge when it is thinnest there.

When the temperature of the plate exceeds a certain limit the phenomenon of the *spheroidal condition* of water is produced. According to Boutigny, this may take place when the temperature of an iron plate is as low as 350° Fahr. When the shape or position of the heating-surface prevents the ready escape of the steam from it, as in horizontal water-tubes, or when the fires are urged much in a boiler with defective circulation of the water, or when the thick scale which has accumulated on a heating-surface cracks and becomes detached by the expansion of the overheated plate, the temperature of the latter may have become high enough to produce the spheroidal condition of the water; and although the repulsion between the water and the plate may continue only for a few seconds, this time may be sufficient, with an intense heat, to soften the iron so that it is forced outward by the steam-pressure. In the depression thus formed sediment is very apt to lodge and accumulate, favoring a repetition of the process, and by alternate heating and cooling this part of the plate will be either cracked or burnt out.

Temperature.	Relative tenacity.			
	Experiments made by committee of Franklin Institute, 1832–33.	Experiments made by Kollmann, 1877–78.		
Degrees Fahr.	Wrought-iron.	Fibrous wrought-iron.	Fine-grained wrought-iron.	Bessemer steel.
32	100	100	100	100
212	....	100	100	100
392	93.8	95	100	100
572	91.7	90	97	94
932	66.8	38	44	34
1292	30.0	16	23	18
1652	....	6	12	9
1832	....	4	7	7

Experiments on the tenacity of wrought-iron and steel at different temperatures, made by Kollmann in 1877–78, give much lower results for the tenacity of these metals at temperatures exceeding 570° Fahr. than the experiments made by a committee of

the Franklin Institute in 1832–33. The foregoing table, showing the relative tenacities of wrought-iron and steel at different temperatures, gives a brief summary of the results of these experiments.

3. Strains produced by sudden Variations and great Differences of Temperature.—If the ends of a plate are rigidly fixed so that it is incapable of altering its length, while at the same time it cannot bend sideways, an increase in temperature of 1° Fahr. will subject it to a compressive stress of about 150 lbs. per square inch, and a decrease of 1° Fahr. will produce under the same conditions a tensile stress of equal intensity ; and these stresses are totally independent of the sectional area of the plate.

When steel boiler-plates were first introduced great difficulty was experienced from the unequal expansion of plates which had left the rolls at different temperatures. The coldest-rolled plates expanded most on being reheated the first time ; and, consequently, when plates that had left the rolls at different temperatures were riveted together there was a constant strain on the joint, which often resulted in the fracture of the plate. This difficulty was overcome by annealing all the plates after they left the rolls.

The cracks which are frequently found in the lap-joints of furnaces, extending either from the rivet-holes to the edge of the plate or from hole to hole in the seam, are probably in most cases caused by the unequal heating and sudden cooling of the plates. The double thickness of plates at the lap in contact with the fire causes their temperature to be greater than where only a single thickness exists, and a corresponding tendency to expand. When a current of cold air rushes in through the open furnace-door and impinges against the heated and expanded joint, it cools off the outer plate suddenly, producing a tendency to contract. But the inner plate of the lap still retains its original temperature and resists contraction, thus throwing a sudden tensile strain on the outside plate, which, if sufficiently severe or often repeated, will produce fracture, especially as the iron around the rivet-holes is frequently already injured by punching or drifting.

Long furnace-flues should be allowed to accommodate themselves to the expansion and contraction due to the varying temperatures either by applying the Bowling hoop to them (see section 6, chapter ix.) or by turning the flanges which secure them with a large radius. If this is not done they are apt to crack through the bend of the flanges, especially when they are secured by angle-irons, or the end plates of the boiler to which they are attached have to buckle with the longitudinal expansion of the flues, and the constant repetition of this movement inevitably results in the destruction of the plate ; the more rigidly the plates are stayed the more severe is this strain on them.

A great difference of temperature exists often in the upper and lower half of furnace-

flues, especially when the feed-water is cold. The resulting unequal expansion throws severe strains on the longitudinal and transverse joints, besides weakening flues by distorting their circular cross-section.

These strains are very severe in the case of the shell of cylindrical boilers of large diameter, the bottom of which has the temperature of the feed-water while the upper portions have the temperature of the steam. The difference of these temperatures may amount to more than 200° Fahr. The effect of these strains is that the circumferential seams at the bottom are frequently leaky, while the longitudinal seams are generally tight. Many boilermakers double-rivet the circumferential joints on this account, although single-riveting would be sufficient to resist the strains produced by cold-water pressure. In several double-end boilers these strains have caused the fracture of the plate between the rivet-holes in the circumferential seams. On account of these strains the shell of such boilers should be made of a soft, ductile iron. The difference of temperature should be reduced as much as possible by facilitating the circulation of the water and by increasing the temperature of the feed-water.

The general rules and regulations prescribed by the Board of Supervising Inspectors of Steam-vessels (1879) provide that "the feed-water shall not be admitted into any boiler, on board of any steam-vessel subject to the jurisdiction of this Board, at a less temperature than one hundred (100) degrees Fahrenheit for low-pressure boilers, and one hundred and eighty (180) degrees Fahrenheit for high-pressure boilers; nor shall cold water be admitted into any such boiler while the water is at a less temperature than the surrounding atmosphere." Boilers carrying a steam-pressure exceeding 60 pounds to the square inch are to be considered as high-pressure boilers.

Plate XXXVI. represents some specimens of rivets taken from the bottom of a circumferential seam of an externally-fired, cylindrical flue-boiler, about 4 feet in diameter. The seam was situated in the furnace near the bridge-wall, and had repeatedly given trouble by leaking. The expansion and contraction of the lap had evidently caused the fracture of the rivets, gradually detaching the conical heads from the shanks, so that they were held in many cases only by a few fibres. The corrosion of the extremity of the detached shanks indicates that this action had extended over a considerable length of time. The unequal strains thrown on the rivets had been intensified by the leverage of the rivet-heads, and the fracture of the fibres, commencing at the circumference of the shank, had taken place, as it gradually extended toward the centre, in nearly every case at the same distance from the outer surface of the conical head, so that the detached heads were concave at the side where fracture had taken place. This uniformity in the appearance of the fractures seems to indicate that the iron of the rivets

was made brittle by hammering after the rivets got cold, the injury extending to a nearly uniform depth from the surface.

In locomotive boilers the difference of the temperatures of the flat sides of the shell and of the fire-box, which are tied rigidly together by closely-spaced stays, produces often very destructive strains. Since the top and side plates of the fire-box are not at liberty to expand freely, they pucker at the ends, causing the joints to leak and often fracturing the plates or the stay-bolts. The tube-sheet is likewise distorted, the outer rows of the tube-holes become oval, and the tube-ends either crack or leak. These evil effects may be greatly lessened by turning the flanges with a large radius, which allows the plates to accommodate themselves to the varying movement of expansion and contraction. It has also been proposed to use flexible stays instead of screw-stays near the extremities of the side and front plates of the furnace.

4. Formation of certain Saponaceous Deposits in Land Boilers.—In an article by M. Maurice Jourdain, in the first report of the Parisian Association of the Owners of Steam-apparatus, an account is given of the formation of a peculiar deposit in land boilers under certain conditions. When boilers are fed with water containing greasy matter certain particular circumstances, still imperfectly defined, cause a light grayish, pulverable deposit to cover the iron directly exposed to the fire. This powder, which, according to chemical analysis, is composed principally of lime-salts and magnesia and greasy matter, possesses the peculiar property of being impervious to water.

"It is very easy," says M. Jourdain, "to understand the effect produced by this lack of permeation. The water, running along the plate without wetting it, is maintained in a spheroidal state. Under these conditions the iron plate can be highly heated without communicating any sensible amount of heat to the water, which covers without touching it. This state continues until the temperature of the iron is sufficiently high to burn out the lime-soap which overlays it. At that moment the iron plate, suddenly uncovered, is brought into contact with the water, which causes a partial explosion and a sudden cooling of the metal. This suffices to deteriorate the boiler.

"In fact, the deteriorations observed in the cases where that gray powder existed have always been very serious."

In 1864 six boilers erected in the iron-works of Mr. Borsig, in Silesia, showed, during the first days of use, leaks from the joints of the iron plates exposed to the fire, which daily increased. When the boilers were stopped a great many cracks were discovered extending over a large surface, besides loose rivets, blisters, etc. Three

other boilers put in operation to replace the former ones did not give any better result. After forty-eight hours of use the effect of irregular heating or overheating of the iron was indicated by the escape of water and other phenomena. Once, while one of these boilers was in operation, a rumbling noise was heard, followed by a detonation accompanied by a violent jerking of the boiler, as if it were at the point of exploding. These phenomena ceased after precautions had been taken to prevent the presence of greasy matter in the feed-water.

Several other cases are described where equally destructive effects were produced by the formation of the powdery substance, which always contained carbonate of lime and magnesia mixed or combined with greasy matter.

In discussing these observations M. Delaunay states that he found that the soap formed by the combination of carbonate of lime with fatty matter does not adhere to the plates of a boiler, and is permeable; and he concludes, therefore, that the presence of magnesia may be essential to give to this substance the peculiar character which produces such destructive effects on boilers. He continues then: "A final peculiarity which we can select from the detailed reports made on various experiments where the said phenomena have occurred is that the feed-water which caused them produced always but little incrustation.

"It is comprehensible, in fact, that, since the greasy matter contained in the condensed water is always present in small quantities, its isolating action cannot become manifest when it is surrounded, so to speak, by a mass of chalky matter, the precipitation of which operates unceasingly, adding at each instant new layers of deposit to the old ones. The conditions which seem to determine the production of the phenomena of isolation and of the spheroidal state, the consequences of which we have described, are, therefore: 1st, the relative purity of the water; 2d, the presence of magnesia in the water. Let us, however, remark that these conclusions are only probable, and cannot be considered as scientifically demonstrated." (*L. Delaunay*, '*Etudes sur les Générateurs à Vapeur à Haute Pression.*')

5. Corrosion of Steam Boilers by Sulphuric Acid present in the Soot.— Several years back the attention of French engineers was directed to the rapid corrosion of land boilers on the exterior surfaces of plates where soot was allowed to accumulate. Several such cases are described in an article in the 'Annales des Mines et des Ponts et Chaussées,' 1876.

In one case the iron was reduced in thickness from 0.47 inch to 0.067 inch in five years. The corrosion, which was wholly on the outside, was attributed by Mr. Douville, Mining Engineer, to the action of the oxygen and sulphurous acid in the gases of

combustion in the presence of water. He took large scales of the oxide of iron from the corroded parts, and he found therein sulphur, but was not able to determine its state of combination.

In another similar case "two specimens of the deposits left by the smoke on the injured iron have been analyzed; they gave between 52 and 53 per centum of sulphate of iron. One gave 1.42 per centum of free sulphuric acid, the other gave 12 per centum nearly. The deposits formed on the rest of the boiler also contained sulphuric acid, but in notably less quantity, and no sensible deterioration of the metal had resulted from it."

Some examples of exterior corrosion in consequence of the condensation of the aqueous vapor in the smoke on the cold parts of boilers have been pointed out by Meunier-Dollfus, Director of the Alsatian Association of Steam Boilers. Respecting a case described by him it is stated that the corrosion was principally on the cold or but little warmed portions of the heaters, and had for first cause the sulphurous acid dissolved in the water of condensation deposited from the smoke. It was ascertained that in the presence of air and of this watery acid there was first oxidation of the iron and then formation of the sulphate of the oxide of iron.

The following conclusions are drawn from the investigation of the cases considered: "When the smoke-deposits on boiler-surfaces distant from the furnace are rendered moist by any accidental cause, the sulphurous acid in the gases of combustion determines the attack upon the metal by the formation of the sulphate of the oxide of iron.

"The attack can take place, while the boiler is in use, on such of its metallic surfaces as may be wetted by leakage from the boiler itself, or by water infiltrated through the masonry or derived from the condensation of the aqueous vapor in the gases of combustion by contact with surfaces relatively cold. It can also be produced, while the boiler is out of use, by means of the humidity of the air in the flues." (*See Journal of the Franklin Institute, November*, 1877.)

The following is an extract from an essay on "The Acid Products of the Combustion of Coal," by M. Vincotte, translated in the *Journal of the Franklin Institute*, March, 1880:

"The gases of combustion deposit on the heating-surfaces of boilers different substances of great importance as regards the durability of the metal composing those surfaces and its power of transmitting heat. These substances are principally soot, tarry matter, sulphuric acid, and ammoniacal salts.

"The quantity of soot in the gases depends on the kind of coal consumed and on

the intensity of the chimney-draught; but whether great or small, a portion is always deposited on the heating-surfaces.

"The soot in immediate contact with the surfaces is cooled by them below the temperature of combustion; but when the deposit attains a certain thickness the portion most distant from the surfaces burns whenever the hot gases of combustion passing over it contain sufficient free oxygen. The thickness of the soot-deposit which escapes combustion depends on the temperature of these gases at any particular point considered, and should, therefore, after the boiler has been some time in use, be found to increase from the furnace to the chimney.

"On all the heating-surfaces where the gases of combustion have a sufficiently elevated temperature to burn the outer portion of the soot-deposit the unburnt inner portion is found covered with a white layer of ash from the burnt portion, and this ash has a thickness limited only by its cohesion; generally it increases until the surfaces are swept.

"On the heating-surfaces where the temperature of the gases of combustion is too low to ignite the soot the latter remains black, and its thickness continually increases until it falls off by its own weight, which does not happen soon."

After giving the analysis of several specimens of soot-deposit taken from different boilers and heaters, which contained in nearly every case various quantities of *ferric sulphate*, *ferrous sulphate*, and *free sulphuric acid*, he continues:

"There does not appear a satisfactory theory of the formation of the sulphuric acid. It may, indeed, be said that all the coals burned in boilers contain sulphur, whose combustion would naturally produce sulphurous acid, which encounters amid the gases of combustion free oxygen, aqueous vapor, and other substances necessary to its transformation into sulphuric acid; but what those substances are or how they react is unknown. Be that as it may be, it is found on all the heating-surfaces not coated with pitch, and forms there, in immediate contact with the iron beneath the soot, a very thin layer of ferric sulphates, with which it remains mixed.

"The quantity of acid thus found on the heating-surfaces is so much the greater as their temperature is lower. It increases from the furnace to the chimney, and when the boilers are fitted with feed-water heaters the acid is most abundant on them, where it is found not only in contact with the metal, but throughout the whole layer of soot there, which is impregnated with it. . . . .

"To sum up, when a boiler is heated with semi-fat coal, and examined after the fire is withdrawn, the heating-surfaces are found covered with the following products of the combustion:

"1. Above the fire is a thin layer of very dry pitch mixed with soot and ordinarily a little acid and astringent; if, however, portions of the surface have been overheated the pitch will have disappeared from them. Upon the pitch is some clinker, derived from the ash mechanically carried up, which, being intercepted by the rivet-heads and other projections, is partially fused there.

"2. Farther on are found three very distinct layers. The first, in immediate contact with the iron, is thin and white; it is composed of from 80 to 90 per centum of ferrous and ferric sulphates, 2 to 3 per centum of free sulphuric acid, a small quantity of ammoniacal salts, sulphate of lime, etc. Under this layer the iron is white and clean; sometimes it is brilliant.

"The next layer is black soot mixed with a little acid, and with salts of iron and ferric oxide, derived probably from anterior decompositions. This layer of black soot increases in thickness as we proceed towards the chimney.

"Lastly, the outer layer is composed of a white or pinkish substance, very soft, very adhesive, and very dry, composed of alumina, silica, and sulphate of lime, and, when of great thickness, its external portion sometimes melts and forms small, greenish, vitreous grains. Ordinarily the layer is compact, but sometimes when very fat coal is used it is flaky.

"3. Still farther towards the chimney the outer layer diminishes in thickness and disappears after having become grayish. There is then found only the white and acid substance in contact with the iron, and the black soot, which sometimes becomes from $\frac{3}{8}$ to $\frac{3}{4}$ of an inch thick when not removed by sweeping.

"With fat coal the difference is that the layer of pitch extends farther at the expense of the surface covered by the acid.

"As soon as the boiler is put out of use the different products just enumerated become rapidly modified, and an examination finds them under very varied forms.

"The sulphuric acid quickly attracts the surrounding humidity, becomes diluted, and penetrates by imbibition into the soot which absorbs it.

"The mixture of ferrous and ferric salts acts in an analogous way, depending, however, in a very notable manner on its composition, whether ferrous or ferric. When there is only a little ferrous sulphate it attracts enough humidity to furnish its water of crystallization, and crystallizes into a very dry substance, which is only transformed slowly, and has not, under ordinary circumstances, further action on the metal. The ferric salts, on the contrary, when in certain quantity, are deliquescent or not, according to the hygrometric state of the flues. I have had specimens which in one corner of my laboratory were deliquescent and in another warmer corner were not.

"The soot, when sufficiently moistened, diminishes greatly in volume. It often becomes loosened, twists like a peeling, and hangs from the heating-surfaces in tatters, of which a large portion falls at the first accession of heat.

"The acid, once slightly diluted, attacks the iron. The ferric salts act in the same manner, and after a time, depending upon the humidity of the flues, the white layer in contact with the iron grows yellowish, and then, little by little, changes into a thick layer of rust impregnated with sulphate of iron. It is by the appearance of this layer, after the boiler has been some days out of use, that we ascertain whether the flues are humid. If it grows yellowish after two or three weeks we can conclude that the thickness of the metal is rapidly undergoing a general diminution, and this corrosion is due to humidity, whose cause should be discovered and removed.

"As regards the preservation of boilers, all the preceding is summed in some leading facts :

"*First.* Nearly all the heating-surfaces of a boiler are covered with sulphuric acid, but this acid attacks them only in an insensible manner. Boilers forty years old are met with whose heating-surfaces have always been covered with acid without diminishing their thickness $\frac{1}{25}$ of an inch.

"*Second.* As soon as this acid in any way acquires humidity it becomes very corrosive and rapidly pits the iron.

"*Third.* An examination of the flues shows at a glance, simply by the appearance of the products, if humidity be present. If it be, the cause must at once be discovered and the effects ascertained."

6. Corrosion due to the Presence of Oxygen and Carbonic Acid in Water.—The most common cause of the corrosion of boilers is the exposure of unprotected iron surfaces to the combined action of the atmospheric air and of water. The air present in the feed-water and the natural moisture of the atmosphere are sufficient to produce *rusting;* but this action is more intense when, after the fires are hauled, the boilers are only partly emptied and are left standing for some time in a damp condition, or when leaks keep the outside of boilers wet.

It has been asserted by some engineers that distilled sea-water has a peculiarly destructive effect on iron. The corrosive action of such distilled water is, however, to be ascribed to the presence of some corrosive substance carried over during the process of distillation, or of atmospheric air, oxygen, or carbonic acid; because perfectly pure water does not produce corrosion in iron at ordinary temperatures. The carbonic acid may either be originally present in the free state or may be produced by the decomposition of some carbonate.

The following account is given by M. Cornut, Chief Engineer of the "Association du Nord," of experiments made by Scheurer-Kestner and Meunier-Dollfus to test the action of different waters on iron.

They took three flasks, each holding ten litres, and filled them with water.

The *first* flask contained water free of lime-salts but highly aerated.

The *second* flask contained water holding lime-salts in solution, and likewise air and carbonic acid.

The *third* flask contained distilled water from which the free oxygen had been removed by boiling.

In each flask a well-cleaned and polished bar of iron was placed.

All necessary precautions were taken to ensure exactness in these experiments, which continued several weeks.

The *first* flask was the first to show signs of oxidation. Yellow streaks soon made their appearance in the water and the bar became gradually covered with pustules of rust. After all the oxygen of the air had been consumed the phenomena of oxidation ceased; and the bar, having been taken out of the flask and cleaned and then put back, remained as bright as if it had been varnished.

The *second* flask showed the same phenomena of oxidation, but they appeared more slowly, and the yellow streaks were intermixed with white streaks formed by lime-salts which were precipitated. After the lapse of some time the iron bar was taken from the flask, cleaned and put back, and again became covered with a layer of oxide. Consequently the lime-salts deposited on the metal interfered with and retarded its oxidation.

The *third* flask showed no sign of oxidation; the bar remained bright.

Experiments on the oxidation of iron by Professor F. Crau-Calvert, of Manchester ('Memoirs of the Philosophical Society of Manchester,' 5th vol., 5th series), proved that no oxidation takes place in iron immersed in dry oxygen or in pure and dry carbonic acid. Damp oxygen acts feebly, damp carbonic acid not at all. A mixture of oxygen and carbonic acid in a dry state does not oxidize the iron; a mixture of the two gases in a damp state produces a very rapid oxidation of the iron. First peroxide of iron is formed, then carbonate, and finally a mixture of oxide and hydrate of the sesquioxide. An iron rod plunged into a bottle filled with the ordinary water of the city of Manchester, containing in solution oxygen and carbonic acid, was covered with rust at once. An iron plate, immersed in a bottle filled with the same water which had been boiled so as to remove the oxygen and carbonic acid, showed no trace of oxidation after several weeks.

The 'Third Report of the Admiralty Committee on Boilers' contains the following

passage relating to the destructive action of water in combination with oxygen and carbonic acid on boilers :

"The water with which the boilers are filled, and likewise that which is supplied to make up the quantity changed by blowing-off and the unavoidable waste of steam, contains air and carbonic acid in solution ; the air dissolved by water contains a larger proportion of oxygen than ordinary atmospheric air, and it is this oxygen which contributes so greatly to the corrosion of iron."

From a series of experiments, carried out by the committee to illustrate this action of oxygen upon iron immersed in water under different circumstances at the ordinary temperatures, it appears that pure distilled water perfectly free from solid matter allows of more corrosion than sea-water.

"Mr. Lant Carpenter gives as the mean of thirty analyses the following relative proportions of oxygen, nitrogen, and carbonic acid in 100 volumes of the gases dissolved in surface sea-water: Oxygen, 25.1 ; nitrogen, 54.2 ; carbonic acid, 20.7 ; the average proportion of these mixed gases amounts to 2.8 volumes in 100 volumes of water ; and in order to avoid the corrosion due to the presence of these substances, and also the variable conditions of density and scale, the discontinuance of blowing-off, together with the substitution of distilled sea-water (where fresh cannot be carried) for sea-feed to make up waste, would be advisable.

"Perfectly dry air has no action upon compact iron at the ordinary temperature. On the other hand, water perfectly free from air is also without action upon iron at the ordinary temperature. Water in the state of steam, when passed over iron heated to a sufficiently high temperature, does oxidize it. . . .

"Much misapprehension appears to exist with reference to the action of '*pure water*' upon iron, as, after what has been stated, it will be seen that the corrosion or oxidation which has been described by many of the witnesses and others to the action of pure water *per se* should properly be attributed to the oxygen contained in the air dissolved by such water, the water acting as a means of transfer for the oxygen to the iron—a property which it would possess to an unlimited extent."

7. Corrosive Action of the Chloride of Magnesium.—The affinity of magnesium for chlorine is so weak that even at the temperature of boiling water the chlorine decomposes the water, forming hydrochloric acid and magnesia according to the following equation :

$$MgCl_2 + H_2O = MgO + 2HCl.$$

The committee appointed by the British Admiralty to investigate the deterioration of

boilers made experiments from which they inferred that this decomposition takes place much more slowly than has frequently been believed to be the case.

"Some chloride of magnesium was dissolved in water and evaporated to dryness; the process was repeated (say 20 times) in order to see if the chloride would be decomposed completely. At the end of the experiment the residue (after heating strongly) was digested with water, filtered, and a solution of nitrate of silver added: an abundant precipitate of chloride of silver showed that the decomposition was very incomplete.

"It was ascertained that so long as the contents of the dish were fluid, or even after solidification commenced, the water evaporated showed no signs of acidity, but that, when the last portions of the water were passing off, very marked acid reaction took place, and the pungent vapor of hydrochloric acid was distinctly perceptible.

"From these experiments it may be inferred that no decomposition of chloride of magnesium occurs during the simple ebullition and concentration of sea-water (as had been suggested), and that the water distilled from sea-water, when carefully done, contains nothing more than that distilled from fresh or land water. When the distillation is conducted on a large scale and rapidly, varying quantities of the saline contents may be carried over mechanically; but the evil effects attributed to the use of distilled sea-water are doubtless due to other causes.

"In the presence of iron, as will be shown further on, the stability of chloride of magnesium is affected, with the production of proto-chloride of iron (ferrous chloride); but the constant though feeble alkalinity of sea-water precludes the action, or even the existence, of hydrochloric acid in the free state.

"The instability of this salt [chloride of magnesium] in the presence of iron, even at the boiling-point of water, and in the absence of air, as pointed out by Professor Wagner (*Dingler's Polytechnisches Journal*, October, 1875), would be considerably increased at the higher temperatures at present realized in marine boilers. . . .

"In one of the experimental tubes at Sheerness (A No. 21) there were dissolved 3,000 grains of chloride of magnesium in rain-water; after six months' work the rod in the tube was found to be corroded somewhat irregularly from below upwards, which is contrary to the usual direction. . . .

"The water in this tube was examined, and found to contain proto-chloride of iron in solution, while at the bottom of the tube there was a deposit of red oxide of iron which contained small quantities of magnesia; now, proto-chloride of iron and hydrate of magnesia react upon each other, with the reproduction of chloride of magnesium and oxide of iron, which is gradually converted into the red oxide by the

action of air; the proportion of iron in solution was equal to 6.37 grains in one gallon. A continuous reaction such as this goes far to explain why marine boilers raising steam from sea-water suffer so much more from corrosion than boilers on shore fed with fresh water.

"Another source of corrosion connected with the presence of chloride of magnesium is due to the hygroscopic nature of this salt. When chloride of magnesium is present in the deposits formed in the boiler it absorbs moisture eagerly from the atmosphere, and thus offers the means of transferring oxygen to unprotected iron surfaces.

"The phenomenon known familiarly to engineers as *sweating* proceeds from the same cause, and may always be seen in the form of globules on the surfaces of old boilers in damp weather. These globules are acid to test-paper, and contain iron in solution in the state of protoxide; on exposure to the air they become covered with a thin film of peroxide of iron; and if in that condition the drops are gradually dried up the film (hollow) remains, and if the surface of the iron be kept quite dry decay ceases, but recommences when the temperature of the iron falls to that of the atmosphere and allows of fresh moisture being deposited." (*Admiralty Committee on Boilers, Third Report.*)

8. Corrosive Action of Fatty Acids.—"The following is an explanation of the changes which a fatty body undergoes in presence of certain calcium and magnesium salts, especially the carbonates. When fatty matters are heated to a temperature of about 140° or 160° Fahr. with calcium carbonate, they form a kind of insoluble lime-soap, which adheres to the sides of the containing vessel. As the temperature rises, however, this lime-soap is decomposed into free fatty acid—usually oleic acid—and a readily-decomposable variety of basic lime-soap. These two substances at once seize hold of the iron and dissolve it. The presence of the grease is not less destructive even if the proportion of calcium and magnesium salts is very low, as, under great pressure, a trifling amount of lime-salts will suffice to determine the re-solution of a neutral fat into free acid and glycerine." (*G. R. Tweedie, in "Iron," Sept.* 21, 1878.)

Such a decomposition is, in fact, effected by water alone when it is made to act upon fat at high temperatures and pressures, and this process, called *water-saponification*, has been made use of to separate stearic acid from tallow for the purpose of manufacturing hard candles. The temperature at which this water-saponification takes place is, according to some authorities, about 400° Fahr., while others assert that even a temperature of about 270° Fahr. would be sufficient for the process. In several instances it has been found that the iron boilers used in this process of water-saponification for the manufac-

ture of candles corroded rapidly and in a very irregular manner, the plates being deeply pitted, especially in the neighborhood of the water-level.

The corrosive influence of water and fatty acids upon iron at ordinary boiler temperatures was tested in 1864 by Professor A. W. Hofmann, of the Royal College of Chemistry, by direct experiments which are described by him in a letter to Messrs. Humphrys & Co., appended to the 'Report of the Admiralty Committee on Boilers.' He says:

"Iron tubes containing rods of different varieties of iron, and fitted with hermetically-closing caps, were charged with water and stearic acid, the latter having been separated from tallow by the ordinary process of lime-saponification. These tubes were exposed for three weeks to a temperature of from 264° to 285° Fahr., corresponding to a pressure of from 2½ to 3½ atmospheres. On opening them the inner surface of the tubes, as well as the iron rods, proved to be powerfully corroded; a large proportion of oxide of iron was found in conjunction, and apparently in combination, with the fatty acid floating in the liquid. Under the circumstances described this effect can have taken place only by an actual decomposition of water. Indeed, when the experiment was repeated with iron rods enclosed with water and fatty acids in a glass tube the ends of which had been drawn out and sealed before the blow-pipe, it was found that after six hours' exposure to a temperature of 356° Fahr., corresponding to a pressure of ten atmospheres, very appreciable quantities of hydrogen had been evolved. When the drawn-out point of the tube was softened in the blow-pipe flame the compressed gas forced its way through the glass and exploded with a loud sound. To ascertain the dependency of this effect, which was observed in several consecutive experiments, on the fatty acid itself, and not on traces of mineral acids possibly contained and masked therein, the experiment was repeated at the reduced temperature of 212° Fahr., when no hydrogen was found to be evolved. Had a trace of free mineral acid been present hydrogen would have inevitably been disengaged, even at the temperature of boiling water. It was, moreover, established by careful experiments that iron, when heated with water alone to 356° Fahr., yielded no trace of hydrogen.

"The rapidity of the corrosive action of fatty substances, in the presence of water, upon iron considerably increases with the augmentation of temperature, but even at ordinary atmospheric temperatures it takes place in a lesser degree."

The iron-soap formed by the action of fatty acids on iron is decomposed again by heat into oxide of iron and free fatty acid. A series of observations and experiments made on this subject by Professor V. Wartha, of Buda-Pesth, are recorded in *Dingler's Polytechnisches Journal.* Wartha was led to this study by the analysis of deposits

found on the damaged parts of the heater of a steam-engine. The analysis of that deposit gave him an oleate of the oxide of iron and free oleic acid.

"I made then by synthesis," says Prof. Wartha, "a comparative trial with free oleic acid, which, after having remained a long time in contact with the air, turned a yellowish brown. I then took a few cubic centimetres of that fatty acid, added water and mixed it with iron filings, then heated it, when the mass began to swell and boil and disengaged great quantities of hydrogen, and a glutinous mass of oleate of iron remained, brown in color and soluble in ether. This mass contained 11 per cent. of oxide of iron, and was in every respect like the substance found in the heater.

"The explanation of the reactions which I have just described is very simple. In the factory spoken of the exhaust-steam is used to heat the feed-water. The fatty acid —that is to say, the oleic acid—formed by contact with steam and under the influence of heat, is carried off with the condensed steam, and arrives thus in the heater. In that apparatus the drops of condensed oil stick to the sides as a pasty mass, and under the influence of heat the iron is then attacked at the point of contact.

"Under the influence of pressure, and with the aid of hot water, oxide of iron and free fatty acid are continually formed, and the latter combines with a fresh portion of iron to form oleate of iron; so that the drop eats away the iron, and burrows, so to speak, in the metal. After a very short time the metal plates were thus perforated and the apparatus commenced to leak.

"By the preceding explanation it is easy to account for the manner in which a comparatively small quantity of oleic acid can, in a very short time, perforate an iron plate 7 millimetres (0.276 inch) thick."

Regarding the action of fatty substances upon copper Professor Hofmann speaks as follows in the letter referred to above:

"Under like influences the behavior of metallic copper greatly differs from that of iron. At ordinary atmospheric temperatures fatty acids have no action upon copper, provided atmospheric air be excluded, and, indeed, even at high temperatures metallic copper resists the action of fatty acids in a remarkable manner. The immense copper condensers used at Messrs. Price & Co.'s Candle-works for condensing the products obtained by superheated steam saponification are week by week exposed to the simultaneous action of water and fatty acids at temperatures varying from 520° to 550° Fahr.; they remain perfectly intact. It is only when the process is interrupted from Saturday night till Monday morning that air gets into the tubes and that a slight corrosion takes place, which is indicated by the appearance of a bluish film on the inner surface of the condenser-tubes. The experience collected at Price's Candle-works, for

which I am indebted to the kindness of Mr. Wilson, entirely agrees with the results of experiments which I have made myself upon the subject. In these experiments rods of copper were enclosed together with water and fatty acids in iron tubes and submitted to a temperature of from 264° to 285° Fahr., corresponding to a pressure of from 2½ to 3½ atmospheres; under these conditions the copper rods were found to be scarcely altered. Similar results were observed when copper rods were heated with water and fatty acids in glass tubes as high as 356° Fahr.; the fatty acid remained colorless, and not a trace of hydrogen was evolved. On the other hand, copper plates boiled with water and fatty acids in an open flask, provided with a glass tube for the purpose of condensing the steam and fat, were powerfully attacked in the course of a few hours."

The water in boilers generally contains a sufficient quantity of lime-salts to determine the decomposition of fatty bodies, and, when the pressure of the steam exceeds 30 pounds per square inch above the atmosphere, its temperature is probably sufficient to cause the decomposition of tallow and of the animal and vegetable oils used for lubricating the steam-cylinders and valves. The conditions necessary for the decomposition of these fats and the combination of their acids with copper exist after the engines are stopped and atmospheric air enters the valve-chests, condensers, pumps, and pipes. When the engines are started again the copper salts thus formed are carried along with the feed-water into the boilers, and as soon as they are brought there in contact with metallic iron the fatty acids leave the copper and combine with an equivalent quantity of iron, the metallic copper being deposited in the form of minute particles. The quantity of iron primarily oxidized in this manner is relatively small, 32 parts of copper combined with fatty acids being sufficient to oxidize 28 parts of iron. But the secondary action described by Professor Wartha, and consisting in the decomposition of the oleate of iron and the recombination of the free fatty acid thus formed with metallic iron, is a very dangerous source of corrosion.

"The insolubility of the fatty acids in water necessitates their immediate contact with the metallic iron surfaces in order that they may effect corrosion; this contact would be greatest at or near the water-line, until the fat had become so far mixed mechanically with the particles of solid matter in the boiler as to give it a greater specific gravity, when it would, as it does in practice, sink to the bottom of the boiler, where it sometimes assumes the form of globular masses of varying size produced by the rolling motion of the ship." (*See 'Third Report of the Admiralty Committee on Boilers.'*)

An instructive case of the deterioration of iron, apparently due to the action of fatty acids, was described by John A. Tobin, Passed Assistant Engineer, U.S.N., in a lecture delivered before the Massachusetts Institute of Technology.

The bottom sheets of the horizontal steam-drums of the U. S. S. *Swatara*, having a thickness of ⅜ inch, were found to be badly corroded, after two and a half years' use, as high as the water resulting from condensation or carried into the drums by foaming had risen, and particularly along the bottom, which was covered with a dark, greasy sludge mixed with a noticeable quantity of oxide of iron. The corrosion of the plates had taken place in the form of pitting and confluent honeycombing, extending from the merest impressions to a depth equal to the thickness of the plates. Professor Nichols, of the Massachusetts Institute of Technology, analyzed a sample of the greasy deposit, and found therein copper in combination with various fatty acids, such as butyric, oleic, stearic, palmitic acid, etc., and he found also particles of metallic copper present in the scale on the plate. After new bottoms were put in the drums, and wrought-iron steam-pipes connecting the drums with the boilers were substituted for the copper ones, corrosion was almost completely prevented by thoroughly draining and cleaning the drums once a month.

To prevent the action of the fatty acids on condenser-tubes and on steam and feed pipes they are tinned when they are made of copper or brass.

The iron of the boilers may be protected against the action of the fatty acids by a coating of paint or cement or by a thin layer of scale deposited on the heating-surfaces. It is necessary to form the scale before the action of the fatty acids on the iron has commenced, because afterwards it is very difficult to make the scale adhere to the iron, although the water may be maintained in the boiler at a high degree of saturation.

It is also proposed to neutralize the fatty acids by means of carbonate of soda or caustic lime, forming a soap. (*See section* 11 *of the present chapter*.)

Filters are used to remove grease as well as other foreign matter from the feed-water before it enters the boiler. (*See Selden's Filter*, *section* 14, *chapter* xv.)

Perkins avoids entirely the use of lubricants in the steam-cylinders and valves of his high-pressure engines by employing a peculiar alloy for the wearing-surfaces of his valves and pistons.

The formation of fatty acids is completely avoided by using mineral oils instead of animal or vegetable oils or fats for lubricating the steam-cylinders and valves. (*See section* 15, *chapter* xvii.)

To illustrate the difference in the action of tallow or vegetable oils and of mineral oils upon copper, the Admiralty Committee on Boilers placed coils of sheet-brass in common tallow and in mineral oil, and heated them day by day for four months, air having free access to the surfaces. "1029.30 grains of sheet-brass, 12 inches long and 4 inches wide, lost 14.10 grains in the tallow, which was colored green; a similar piece of

the same brass, weighing 1101.40 grains, 11.90 inches long and 4.10 inches wide, immersed in the mineral oil, lost 0.20 grain, the oil becoming darker in color."

9. Corrosion of Boilers by Galvanic Action.—When electro-heterogeneous metals are brought in contact in the presence of acids or saline solutions galvanic action takes place—that is to say, the solution is decomposed, oxygen being disengaged at the electro-positive pole of the galvanic couple.

Copper has a strongly electro-negative character relatively to metallic iron.

The contact of these two metals in the presence of water containing even a minute quantity of saline constituents produces galvanic action; the disengaged oxygen of the water combines at once with the iron, while the hydrogen escapes at the pole formed by the copper, leaving the latter unaltered. In this manner a minute quantity of copper may cause the oxidation or corrosion of a large quantity of iron, if metallic contact is maintained between the two metals.

On account of this action the use of copper tubes in marine boilers is inadmissible. Copper is frequently carried into the boiler by the feed-water; minute particles may be abraded from the copper and composition pipes by the steam and water flowing through them; and the salts formed by the combination of copper with fatty acids are decomposed when they come in contact with the iron of the boiler, and metallic copper is deposited. (*See section* 8 *of the present chapter.*)

Particles of metallic copper have frequently been found on pitted and honeycombed boiler-plates, and this peculiar form of corrosion has been ascribed to the continued galvanic action of these detached particles. It is, however, difficult to decide how much of the corrosion was due to the action of fatty acids and how much of it was caused by the galvanic action of the copper. The Admiralty Committee on the Deterioration of Boilers was inclined to ascribe but a small share of the corrosion of boilers to the latter cause, because the conditions which usually prevail in marine boilers prevent immediate contact between the small particles of copper and the clean metallic surfaces of the iron plates.

Lead is likewise an electro-negative metal relatively to iron. The corrosion of the plates in the vicinity of manholes and mudholes is ascribed to galvanic action caused by the presence of lead, derived from the white and red lead used in making the joints.

In order to prevent galvanic action it has been recommended to obtain electro-homogeneity in the boiler by using only one kind of iron, and iron tubes instead of brass tubes, and, when steel is used, to employ it for every part of the boiler and not in combination with iron. It is, however, impracticable to get large quantities of iron or steel of a

perfectly uniform character, which would be necessary in order to ensure perfect electro-homogeneity.

There is also no direct evidence that brass tubes hasten the corrosion of boilers; on the contrary, the inner surface of iron tube-plates with brass tubes appears generally to be little attacked by corrosion.

The introduction of copper into boilers is prevented by tinning copper and composition steam-pipes, feed-pipes, and condenser-tubes, by using mineral oils as lubricants for the steam-cylinders and valves, and by filtering the feed-water.

Galvanic action may be effectually prevented by keeping the surfaces of the boilers covered with a coating of firm scale or paint.

Feldbacher's plan of lining the interior of the boiler with sheet-copper has been tried on land boilers, and, it is claimed, with good results, corrosion being prevented and incrustation greatly lessened. Another patentee coats the interior of the boiler with a mere film of copper deposited from a solution of cyanide of copper. Other patents have been secured for coating the interior surfaces of boilers with tin, also for enamelling and electro-coppering iron tubes. But none of these plans have come into extensive use in marine boilers.

The film of black magnetic oxide of iron which covers a boiler-plate when it leaves the rolls in a finished state affords to the iron complete protection against corrosion as long as it adheres firmly and remains unbroken. When this film is thick it is easily detached from the plate, and its thickness depends upon the temperature of the iron at the time of rolling. Much of this film is detached by the rough usage to which the plates are subjected in transportation and in the boiler-shop, and by the various processes of boilermaking.

Professor Barff produces a firmly-adhering coating of this black oxide artificially by heating articles of cast or wrought-iron, the surfaces of which have been carefully cleaned, to a high temperature in a closed chamber from which the atmospheric air has been removed, and subjecting them to the action of superheated steam. He states that the temperature required for this process ranges from 650° to 1,500° Fahr.; the lower temperature and longer treatment for wrought-iron, the more rapid treatment and higher temperature for cast-iron. The application of this process to finished boilers has been suggested, but has not been practically tested.

A film of this black oxide protects iron against the attack of powerful acids. From experiments made by Schönbein and others it appears that this oxide of iron has an electro-negative character far greater than copper and nearly equal to that of platinum. This fact may explain the rapid corrosion of iron at places where this film has been

broken, since a powerful galvanic action might be produced under favorable circumstances by the contact of this oxide and of the pure iron, the former forming the negative and the latter the positive pole of a galvanic battery. On this account some manufacturers of boilers remove carefully the whole film of oxide from boiler-plates, since it cannot be maintained unbroken in a boiler and would rather hasten than prevent its corrosion.

The corrosive effect of galvanic action on iron boilers may be prevented by rendering them the negative pole of an electric battery. This is generally and most successfully accomplished by placing within the boiler and connecting with the shell a metal which has a stronger electro-positive character than iron. The metal generally used for this purpose is *zinc.*

10. The Use of Zinc for the Prevention of Corrosion and Incrustation of Boilers.—Very conflicting accounts are given by engineers about the efficacy of zinc in preventing the corrosion of boilers. From the varied testimony offered on this point, and from the results of a series of experiments, the Admiralty Committee on Boilers drew the following conclusions, which are given in their 'Third Report'—viz.:

"Apart from any consideration as to the existence of galvanic action in boilers, the protective value of zinc may be stated as follows: If a boiler is worked in the ordinary manner with sea-water its exposed surfaces will be vulnerable to the action of all the corrosive influences which may be present capable of affecting iron; but if zinc be introduced and applied in the manner which has already been pointed out—*i.e.*, perfect metallic continuity ensured between it and the iron—galvanic action *is* set up between the two metals, and the latter is compelled, by the presence of one of a more electro-positive nature, to assume a negative condition towards corrosion or oxidation.

"Such being the case, the metallic condition of the iron is preserved at the expense of the zinc, which loses in course of time its metallic nature by oxidation, in which latter condition it ceases to afford protection and must therefore be renewed at intervals. In cases where this metallic continuity has not been effected the zinc would share with the iron surfaces of the boiler any corrosive action that might be present, in proportion to the surface exposed, which, in any case, would be relatively small. There would be no electro-chemical relation between the metals, and the different results observed by marine engineers may have depended upon the fortuitous circumstance that in some cases metallic continuity has been unintentionally effected in suspending the zinc from the stays of the boiler; this seems to be a very probable explanation of the discordant opinions held by many as to the protective value of zinc."

Zinc has also been found to prevent the formation of adhesive scale in land boilers fed with calcareous water. The mode of action of zinc in this respect is described by Brossard de Corbigny, in an article in the *Annales des Mines* of 1877, which has been translated for the *Journal of the Franklin Institute* of January, 1878, and from which the following is extracted:

"When the water is but little calcareous the deposits, instead of forming solid and adherent scale, remain in the state of fluid mud, easily removable by simple washing. The iron being clean and not rusted, no picking or scraping is needed, which effects a great economy of time, hard labor, and oversight.

"When, however, the water is strongly calcareous the deposits are as coherent and stony as though the zinc had not been employed; but, what is extremely important, this scale, while acquiring its thickness and hardness, does not adhere to the iron. It can be pulled off by hand, or, at worst, detached without much effort, leaving the iron clean. A simple washing removes it from the boiler, and in this case, as in the previous, picking and scraping are avoided."

The following hypothesis is advanced to explain this action:

"The two metals, iron and zinc, surrounded by water at a high temperature, form a voltaic pile with a single liquid, which slowly decomposes the water. The liberated oxygen combines with the most oxidizable metal—the zinc—and its hydrogen equivalent is disengaged at the surface of the iron. There is thus generated, over the whole extent of the iron influenced, a very feeble but continuous current of hydrogen, and the bubbles of this gas isolate at each instant the metallic surface from the scale-forming substance. If there is but little of the latter it is penetrated by these bubbles and reduced to mud; if there is more, coherent scale is produced, which, being kept off by the intervening stratum of hydrogen, takes the form of the iron surface without adhering to it.

"Zinc introduced into a boiler whose surfaces had been imperfectly freed of scale has the property of detaching the remainder. This effect is well explained by the action of a feeble disengagement of gas beneath the scale, raising it little by little and separating it from the iron."

With the selenious water of the slate-works of Angers the addition of zinc gave no useful result; the scale adhered strongly to the iron; but the writer does not venture to say whether this result was to be attributed to the more coherent nature of pure sulphate of lime, of which the scale almost entirely consisted, or to an insufficient quantity of zinc employed.

The action of zinc with sea-water and acid water was not investigated by the writer.

With water containing free acid, however, no good results would be obtained, as the zinc would be corroded very rapidly and too large a quantity would be required.

De Corbigny recommends that in boilers fed with fresh water from half a pound to one and a half pounds of zinc should be used for each five square feet of water-heating surface during several months, and that the zinc should be used in the form of pigs or cubical masses, and not in the form of chippings or sheets, since in the latter case the electro-chemical action, being exerted over too large a surface, becomes too rapidly exhausted.

Other writers recommend 20 inches of area for each horse-power, and for marine boilers at least a quarter of a pound for each square foot of grate-surface.

The zinc slabs should be distributed over different parts within the water-space of the boiler; but they should not be suspended directly over the furnaces or back-connections, where the oxide of zinc, as it drops down, may cause blistering and burning. When zinc is placed in steam drums and pipes the oxide is sometimes carried by the steam-currents into the valves and causes injury to them.

Fig. 147*a*.

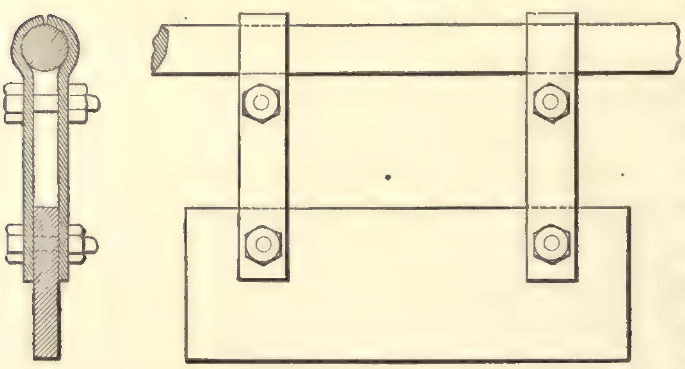


Figure 147*a* shows an arrangement adopted in some boilers for securing the zinc. Zinc slabs about 15″ × 12″ × 1″ are bolted to iron clamps and secured by them firmly to the iron stay-rods or tubes. It is important that, so far as it is practicable, no water should get between the zinc and the iron. To ensure perfect metallic continuity between the two metals the zinc is sometimes soldered to the iron or zinc studs are screwed into the shell of the boiler.

The 'Steam Manual,' issued by the English Admiralty (1879), contains the following instructions regarding the use of zinc in boilers: "The zinc slabs appear to deteriorate either by gradually wasting away or by gradual change of substance. In this latter case, which is the most common, the zinc slab gradually becomes black in color, brittle, and friable; and when it has been long exposed the mere pressure of the hand is sufficient to reduce it to powder. Experience alone will enable the engineer officer to determine how far the zinc may be allowed to decay before renewal; but, until that experience is gained, it is recommended that the zinc should be renewed as soon as the decay has penetrated a quarter of an inch below the surface. Under ordinary conditions of

working the zinc slab may be expected to last, when the boilers are new and the zinc good, not less than from two to four months under water.

"Good zinc is to be used for these slabs. Zinc 'bottoms' must not be used, and the remains of slabs which have been in use must not be recast on board ship for further use. If upon examination they are not sufficiently decayed to be rejected altogether the decayed parts may be chipped off and the slab refitted and kept in use for some time longer. When the slabs are finally removed from the boilers they are to be broken up, the decayed portions thrown aside as useless, and such of the remains as appear to consist of good zinc preserved and returned into store."

11. Action of various Substances upon the Incrustative and Corrosive Ingredients of Feed-waters.—The substances used to prevent the formation of hard, adhesive scale and the internal corrosion of boilers are either introduced directly into the boiler, or they are mixed with the feed-water and made to act upon the salts and acids contained in the water before it enters the boiler. When the latter method is used tanks of large capacity have generally to be provided in order to allow time for the completion of the process of purification. On board of vessels there is generally no room for such tanks, and the action of neutralizing the incrustative and corrosive properties of the feed-water has to take place, in part at least, within the boiler.

Many of the substances recommended for the prevention of incrustation act by a mechanical process, while others effect a chemical reaction, either changing the carbonates and sulphates of lime into soluble salts of lime or producing insoluble salts of lime and magnesia, which are either precipitated as an incoherent mass or remain suspended in the water without agglutinating.

The anti-corrosive remedies are intended especially to change the chloride of magnesium and the fatty acids into substances which do not corrode the metal of the boiler, are not readily redecomposed under the conditions obtaining in a steam boiler, and either pass off with the steam in the form of gas or can be removed from the boiler by the ordinary process of blowing-off.

The selection of any of these remedies should always be preceded by a careful analysis of the water used for feeding the boiler. The presence of certain substances may not only neutralize the effect of a chemical agent, but cause reactions which produce even more harmful substances. In several instances remedies have been proposed which increased corrosion while they prevented incrustation, and others produce practical difficulties which render their use not only inconvenient but dangerous.

The chemical treatment of the water of marine boilers is more difficult than that of the water of most land boilers, on account of the greater number of ingredients con-

tained in the former, and because the method of purification in tanks is not admissible on board of vessels.

"The present large capacity of marine boilers using sea-water alone renders any complete chemical treatment of the water, with the object of preventing corrosion, extremely difficult, as, besides sulphate of lime, sea-water contains salts of magnesium, which, in any attempt towards a condition of alkalinity by lime or carbonate of soda, must be decomposed with production of a bulky precipitate of magnesia; and this, added to the sulphate of lime, may induce priming, and would increase the difficulties resulting from the accumulation of solid matter on the evaporating surfaces, unless the quantity of scale be limited by substituting distilled sea-water for the feed from the sea itself." (*See* '*Third Report of the Admiralty Committee on Boilers.*')

The many anti-corrosive and anti-incrustative remedies offered for sale contain, in some form or other, one or several of the following ingredients combined in a more or less judicious manner:

Oil-cakes, potatoes, and other starchy matter are sometimes put into the boiler to prevent the formation of hard scale by enveloping the particles of lime so that they are deposited in the form of mud; but they produce frothing, and often cause the boiler to foam badly.

Glue, offal of hoofs and horns, tobacco-juice, Irish moss, peat, tow, hemp, etc., act in a similar manner.

Clay likewise causes the lime-salts to settle down as a soft mud; but a grave objection to its use are the gritty particles of sand contained in it, which, carried over by the steam, injure the valve-faces.

Various varnishes or lacquers are proposed to prevent incrustation, but the presence of fatty matter in them often increases corrosion, and they afford insufficient protection against incrustation.

The action of *petroleum or paraffine-oil* as a protection from incrustation is involved in obscurity, but its effects are reported on favorably. It is said to penetrate and rot the scale, making it porous and easily removed, the quantity used being about one quart per week for a twenty-five horse-power boiler. The most efficient quality is the heavy, unrefined oil, the other being soon expelled by the heat. The oil may also be applied to the iron as a coating. (*See section* 14, *chapter* xvii.)

Glycerine has been used in Europe in steel boilers to prevent the adhesion of scale.

Milk of lime or *hydrate of lime* added to water takes up the excess of carbonic acid, which enables the water to hold the carbonate of lime in solution, and the latter is thus precipitated. This process, known as Clark's, recommends itself through its cheapness

and simplicity where tanks can be provided for carrying it on. It is used to purify the water of locomotive and stationary boilers.

A solution of caustic lime being added to sea-water has the effect of decomposing the chloride of magnesium and sulphate of magnesia, with the formation of the corresponding salts of lime, magnesia being liberated.

Hétet (Pharmacien-en-chef de la Marine) has made extensive experiments at Brest with a process of neutralizing the fatty acids contained in the condenser-feed by means of lime-water. The quantity of lime used by him is equal to about one-tenth of the weight of oil used as a lubricant in the cylinders of the engines. The lime forms with the grease an insoluble soap, which is found in the bottom of the boilers or of the purifying-tank. This process should always be carried on in tanks, and the water should be filtered, so that the lime-soap does not enter the boiler, where, under the influence of heat and in contact with the iron, it would probably be decomposed. (*See section* 8 *of the present chapter.*)

Carbonate of soda, *caustic soda*, and *potash* cause the carbonates of lime and magnesia to be precipitated by combining with the free carbonic acid, forming soluble carbonates or bicarbonates of soda and potash.

Carbonate of soda decomposes the sulphate of lime, forming sulphate of soda, which is held in solution, and carbonate of lime, which is precipitated.

By combining with the free carbonic acid in the feed-water these alkalies remove a very harmful corrosive element. (*See section* 6 *of the present chapter.*) They also effectually neutralize the fatty acids by forming a soluble soap which is not readily decomposed.

The 'Admiralty Instructions' relating to the machinery of English naval vessels provide that, with a view to determine the condition of the water in the boilers as regards its acidity, neutrality, or alkalinity, the water of each boiler is to be tested with test-paper at least once per day when under steam. Should the water in the boilers be found to be in an acid condition a small quantity of carbonate of soda is to be supplied to the boiler to neutralize the acid in the water. The soda should be put into the condenser or hot-well, from which it will be pumped into the boilers with the feed-water.

It is recommended to use carbonate of soda in connection with lime or other ingredients for the prevention of scale and corrosion. First, by adding a solution of caustic lime to the feed-water, the chloride of magnesium and sulphate of magnesia are to be decomposed, with formation of the corresponding salts of lime, magnesia being liberated; then carbonate of soda is to be supplied, which will decompose those two

lime-salts, forming carbonate of lime, which is precipitated, and chloride of sodium and sulphate of soda, which remain in solution.

"The use of carbonate of soda in limited quantity, with the idea that it neutralizes the effect of fatty acids in marine boilers raising steam from sea-water, is questionable, because so long as chloride or sulphate of magnesia remains in the water the carbonate of soda is immediately decomposed with the result as stated above. It is only when those two salts have been wholly decomposed, and the sulphate of lime in solution has been converted into carbonate, that the carbonate of soda can be potential as such. So far as the committee are aware this condition has never been realized in marine boilers, and it is for this reason that the benefit which would have resulted from the use of a limited quantity of soda (in fresh water) has not existed. . . .

"The quantity of soda required for the complete decomposition of the magnesium and calcium salts is easily ascertained. To replace magnesium in any of its compounds by sodium it is necessary to make use of 23 parts of the latter for 12 parts of the former, and similarly to replace the calcium (the equivalent of which is 20) also requires 23 parts; or, taking the oxides of these metals, lime, magnesia, and soda, their respective equivalent values are 28, 20, and 31. There are in a ton of ordinary sea-water 19,837 grains of magnesium and 7,233 grains of calcium, and to replace these two by sodium there are required 46,339 grains of that metal. The weight of crystallized carbonate of soda which contains 23 parts or one equivalent of sodium is 143, so that $46{,}339 \times 143 \div 23 = 288{,}107$ grains, or 41 pounds, 2 ounces, 232 grains, are the quantity of crystals of carbonate of soda required for one ton of sea-water." (*Report of Admiralty Committee on Boilers.*)

Hyposulphite of soda keeps the salts of lime in solution; *oxalate of soda* causes their precipitation as a loose deposit; but both are expensive.

Proto-chloride of tin, *silicate*, *phosphate*, and *arseniate of soda* have been tried, but are too expensive, and are not found to answer their purpose sufficiently well.

Chloride of ammonium, or *sal-ammoniac*, acts on the carbonate of lime and magnesia, converting them into chlorides, while their carbonic acid goes to the ammonium, forming carbonate of ammonia, which escapes with the steam. Sulphate of lime is not affected by sal-ammoniac.

Tannic acid forms insoluble tannates of lime and magnesia by the decomposition of the carbonates. These tannates have a low specific gravity and float about the water instead of agglutinating into a crust. The sulphates and chlorides are not acted upon by tannic acid, and will incrustate notwithstanding its presence. Free tannic acid at-

tacks the iron, and its presence in a boiler is a source of great danger. Its effect may be neutralized by carbonate of soda.

Tannin-bearing bodies, like oak and hemlock bark, logwood, catechu, leather, or extracts made of them, are frequently introduced into boilers for the prevention of scale. When the solid bodies are used there is danger of pieces of bark, etc., being blown over by the steam into the valves and pipes.

Tannate of soda, being introduced into a boiler where the carbonates of lime and magnesia are present, gives up to them its tannic acid to form the insoluble tannates, and takes up their carbonic acid to form carbonate of soda, which in turn reacts on the sulphate of lime, converting it into carbonate of lime and bringing it thus under the influence of a fresh portion of tannate of soda. The constant presence of the soda protects the iron from the corrosive action of tannic acid as well as of carbonic acid. The same reaction takes place between tannate of soda and the already existing scale, but more slowly than when the salts are held in solution.

Acetic acid converts the carbonates into soluble acetates; but the iron is equally exposed to its attack. Sulphate of lime is not altered by it.

Molasses, fruit, cider, vinegar, etc., containing more or less acetic acid, have been used in boilers for the prevention of scale.

Tannic acid as well as acetic acid may be advantageously used to purify the water in tanks, the excess of acid being neutralized by carbonate of soda before the water is fed into the boiler.

It has also been proposed, for the purification of water in tanks, to convert the earthy carbonates into soluble chlorides by hydrochloric acid, and to neutralize the excess of acid by filtration through *carbonate of baryta* (witherite) in the form of coarse powder. The soluble chloride of barium thus formed decomposes the sulphate of lime, forming chloride of calcium which is kept in solution, and insoluble sulphate of baryta which is deposited. (*See "Steam Boiler Waters and Incrustations," by Dr. J. G. Rogers, Journal of the Franklin Institute*, 1872.)

When boilers have been fed with water containing a large quantity of organic matter, sewage, bilge-water, etc., it has been found that they remained remarkably free from corrosion, and that the formation of scale with such water was even impossible. The latter effect is probably due to the mechanical action of the organic matter which envelops the solid scale-producing matter as soon as it is formed. The anti-corrosive effect of the organic matter may be ascribed to its absorption of the free oxygen contained in the water.

CHAPTER XIX.

BOILER-EXPLOSIONS.

1. Causes of Boiler-explosions.—Rupture takes place in a boiler either when any part is not sufficiently strong to resist with a reasonable margin of safety the stress produced by the working pressure under ordinary conditions, or when the stress exceeds the ultimate strength of any part in consequence of an excessive rise of pressure in the boiler, or in consequence of great variations and differences of temperature, sudden shocks, weakening of plates by overheating, or similar abnormal conditions.

The weakness of a boiler may be due to the faulty design of its bracing, to the use of inferior material or to injuries received by it in the processes of boilermaking, to bad workmanship, and to gradual deterioration produced by the various causes described in chapter xviii. By exercising vigilance in supervising the building of a boiler, and by conducting with intelligent care the periodical inspections and tests, the actual condition of a boiler may be known, and the steam-pressure which it can bear with safety may be determined accordingly. The original cause of any leak or sign of weakness should always be determined promptly and exactly, and removed in making repairs, otherwise deterioration will not only continue, but may even be aggravated by the means adopted for stopping the leak or strengthening the weak place, especially when the defect is produced by varying bending strains near the attachment of braces or the laps of joints.

Various theories have been proposed to account for the instantaneous generation of excessive pressure within steam boilers by the conjuncture of unusual conditions; several of these will be discussed farther on. Such theories have been brought forward especially in order to explain the frequent occurrence of explosions at the moment preparations are commenced for starting the engines after a boiler has been lying with banked fires for some time.

When the fires are burning actively, and the steam is allowed to accumulate in the boiler by keeping the stop and safety valves closed, the pressure will increase with great activity. In a large marine boiler of ordinary form experimentally exploded at Sandy Hook, N. J., in 1871, the pressure rose in thirteen minutes from 29½ pounds to

53½ pounds per square inch; the furnaces contained a wood-fire, and the water in the boiler stood 15 inches above the upper row of tubes. (*See section* 5 *of the present chapter.*)

A gradual excessive accumulation of steam-pressure is always due to mismanagement and carelessness; it is, however, a frequent cause of boiler-explosions. It cannot take place when the boiler has a safety-valve of sufficient size, properly located and in working order. But when the safety-valve cannot relieve automatically the boiler of an excess of pressure, the latter may accumulate to a dangerous degree rapidly after steam has been raised and the engines are not started or are suddenly stopped, and more gradually when the engines are worked slowly or when the boilers are kept under steam with banked fires. The danger of getting an overpressure of steam in the boiler is greatly increased when the steam-gauge is inoperative or gives wrong indications.

The following circumstances frequently make safety-valves inoperative in practice: When the safety-valve is not placed directly on the boiler, but on the steam-pipe beyond the stop-valve, the latter may be closed and shut off the steam from the safety-valve. In repairing or cleaning the boiler the workmen sometimes plug up the aperture of the valve-chamber from inside the boiler, or put a blank flange between the safety-valve and the escape-pipe to prevent the drip of hot water from leaky valves; several cases of explosion have happened in consequence of the neglect of removing this obstruction before the boiler was closed and steam was raised. In cold weather the escape-pipe may be obstructed by the freezing of the water which has accumulated therein. Safety-valves are sometimes purposely overloaded and tied or wedged down by reckless attendants, or the rise of the valve may be prevented by some obstruction accidentally placed over the valve-chamber. The valve may stick fast in consequence of corrosion or of the accumulation of grease and dirt at the articulations of the lever and in the guide-sleeve of the stem; or it may be prevented from rising by the bending of the lever, stem, or guide-spindle; or the too closely fitted guide-feathers may be jammed in the valve-chamber in consequence of distortion or unequal expansion caused by irregular strains or differences of temperature. To the latter cause the explosion of the boiler of the British armored vessel *Thunderer* was attributed.

To place safety-valves beyond the control of reckless ignorance and carelessness boilers are provided with lock-up safety-valves. For the design, construction, and arrangement of safety-valves see section 11, chapter xv. Safety-valves should be opened by hand soon after steam has commenced to form, and from time to time afterwards while steam is on the boilers, to make sure that they are in working order.

The overheating of plates may be caused by a deficiency of water in the boiler, or

by the formation of deposits of solid matter on the heating-surfaces, or by the accumulation of steam on the heating-surfaces. The overheated parts may be sufficiently weakened to give way at once at the ordinary working pressure either by fracturing or by bulging; or they may be left in a deteriorated condition after cooling down; or their excessive and unequal expansion may produce injurious strains in the parts with which they are connected. When highly-overheated plates are suddenly partially cooled by coming in contact with water their local contraction may produce sufficiently severe strains to rupture them. The ways in which rupture or severe strains are produced in boilers by sudden variations of temperature have been described in section 3, chapter xviii.

Violent shocks are liable to cause rupture in boilers which are in a strained condition in consequence of the steam-pressure within them. Such shocks may be produced by heavy weights falling on the boiler or by the collision or grounding of the vessel. The impact of the water carried upward by the rush of steam when the safety-valve or a stop-valve is opened suddenly may sometimes be sufficient to produce rupture.

Boilers have been severely jarred by the detonation of inflammable gases which had collected in their flues. When a boiler is kept with covered banked fires and tightly-closed damper the gases distilled from bituminous coal, not being able to escape from the flues, may form in them a detonating mixture with the atmospheric air, and, under such conditions, an explosion may occur when, by uncovering the fires, the gases are ignited. More or less severe accidents of this kind have occurred with stationary boilers, but they cannot take place where dampers are not employed, as is usually the case in marine boilers.

Successive explosions of several boilers working side by side have been repeatedly observed, and may be explained by assuming that the explosion of one of the boilers produced severe jars or concussions in the adjoining ones, or that the latter were perforated by detached pieces from the exploded boiler. The rupture of a pipe or drum connected with several boilers may be the cause of their explosion. In a war-steamer the perforation of boilers by shot or splinters in action is a dangerous source of explosion. Locomotive boilers have exploded because the shell was pierced by a broken connecting-rod, or because the steam-dome was carried away by coming in contact with a tunnel or an overhead bridge.

The rupture which takes place in a boiler may be only of a local character and not affect the strength of the boiler as a whole; this is often the case when rivets or small portions of plate are blown out or when small tubes burst or collapse. Or the damage done to any part may cause the opening of seams in such a manner as to allow a gradual

discharge of the steam, thereby relieving the boiler of an overpressure. In these cases the principal danger consists in the liability to scalding by hot water and steam.

The rupture of a boiler is called an explosion when it causes the sudden liberation of large masses of the steam and water confined in the boiler, by which means a dynamic force is developed which aids in the demolition of the whole structure and hurls detached portions with great violence. This will take place when the rupture deprives other parts of the boiler of an essential support, and thus throws additional excessive strains on them, as in the case of broken stays or braces, and rents in circular shells; or when the original weakness extends over a large portion of the structure, which gives way at nearly the same instant, and thereby sets free suddenly an enormous amount of energy stored up in the steam and heated water.

2. Various Theories concerning Boiler-explosions.—The extreme violence of many boiler-explosions has caused the very general impression that some unusual, instantaneously-generated forces are required to produce them. Although it has been demonstrated that the energy stored up in water heated to a temperature corresponding to the ordinary working pressures of steam boilers is more than sufficient to produce the effects of the most violent boiler-explosions, and although it has been repeatedly shown by direct experiment that a moderate and gradually-accumulated steam-pressure in a weak boiler does produce all the phenomena of a violent explosion, there are still many advocates of special theories which explain these phenomena by the sudden generation of abnormal forces within the boiler in consequence of the concurrence of extraordinary circumstances. It is of the gravest importance that the true causes of every boiler-explosion should be clearly understood, in order that their recurrence may be guarded against. The tendency to ascribe explosions to obscure causes rather than to regard them as the natural results of conditions which can be prevented by intelligent care exercised in the design, construction, and management of boilers, has, no doubt, its origin in the desire to escape responsibility for the results of culpable neglect, and has been productive of much mischief by engendering carelessness on the part of owners and attendants of steam boilers. Before accepting any theory as a correct explanation of the causes of an explosion it is not sufficient to prove that the circumstances upon which the theory is based could exist in the case in question, and that they were capable of producing the phenomena observed, but it must be shown by direct evidence that they did exist, or that no other known causes could or were likely to produce the same results.

Little need be said about the theory which ascribes boiler-explosions to an electric discharge; no intelligent explanation has ever been given of the supposed generation of

electricity of sufficiently high tension in a steam boiler to produce the effects of a violent explosion. This idea probably had its origin in an imperfect knowledge of the fact that a current of steam sometimes exhibits electrical phenomena, the development of electricity being solely due, as Faraday has shown, to the friction of the suspended watery particles against the sides of the orifice through which the steam issues.

Another theory assumes the possibility of the formation and detonation of a mixture of hydrogen and oxygen gases in a steam boiler. The hydrogen set free in consequence of the corrosion taking place within a boiler, and the free oxygen contained in the feed-water, are relatively small quantities and so diffused in the mass of steam that they cannot form an explosive mixture.

At a meeting of the American Academy of Sciences (1877) it was shown that steam could be decomposed by simple heat into the constituent gases of water—viz., hydrogen and oxygen. The apparatus consisted of a flask in which water was heated, a tube conveying the steam to a closed platinum crucible, where it was again heated by a spirit-lamp, and a tube which carried thence the superheated steam and the liberated gases to an ordinary pneumatic trough, where the mixed gases were collected in a test-tube while the steam was absorbed. The gases thus collected were exploded by a lighted match. The heat employed was a little over ordinary redness, but did not reach whiteness.

In order that a detonating mixture of oxygen and hydrogen may be formed by a similar process in a steam boiler, a considerable portion of the plates enclosing the steam-space must be raised to a bright-red heat; then the steam must be condensed by the injection of cold water, which must not come in contact with the red-hot plates; the heat of the latter may ignite then the explosive mixture of gases. It is, however, highly improbable that all these essential conditions will be fulfilled in a steam boiler, and it is more likely that rupture will take place in consequence of the weakened condition of the red-hot plates or of their sudden cooling by the injection of cold water.

Several theories have been proposed to explain how large masses of water might be instantaneously converted into steam and thus produce an overpressure in a boiler.

It has been assumed that, especially when the feed-water is very greasy, the phenomenon of the spheroidal condition of water might be produced on a large scale in a boiler, and that when a large mass of water is instantaneously vaporized under these conditions the resulting increase of pressure and the impact of the water thrown up against the shell of the boiler by the suddenly-formed steam would be sufficient to rupture the boiler. While there is reason to believe that this phenomenon occurs frequently on a small scale on the plates forming the furnace-crowns and the combustion-

chamber, and increases their liability to deterioration, there is no evidence that large masses of water have ever been affected similarly in a boiler in such a manner as to generate sufficiently great forces to produce an explosion.

When water is deprived completely of air and is kept perfectly motionless its temperature may be raised many degrees (according to Tyndall, 100° Fahr.) above the boiling-point; but with the slightest agitation the surplus of heat in the water is expended in the sudden formation of an equivalent mass of steam. It is claimed that this phenomenon may occur in a steam boiler and cause its destruction by an instantaneous increase of pressure and by the impact of a large mass of water thrown violently against the walls of the boiler by the steam formed in an explosive manner. To produce this superheated condition of the water the boiler must be supposed to have been standing for a long time undisturbed, with closed valves and low fires, no circulation of the water taking place within it. The sudden opening of the safety-valve or steam stop-valve, or the starting of the feed-pump, would then be sufficient to produce the agitation of the water which causes the sudden generation of steam. In the case of a marine boiler the vessel likewise must lie perfectly motionless during the period of superheating. But we have no direct evidence that these conditions have ever been the cause of the explosion of a boiler, and it is very doubtful whether a large mass of water could be highly superheated in a boiler without circulation.

Another theory is based on the supposition that the steam in the boiler has become highly-superheated in consequence of the overheating of the surfaces in contact with it; that then, by some means, a large mass of water is carried up in the form of spray, and, mingling with the steam, is at once vaporized by the surplus of heat in the latter. The thorough mingling of a large mass of water with the steam is, however, not easily effected in practice, and, even in extreme cases, the whole surplus of heat in superheated steam would not be sufficient to produce a considerable increase of pressure by the vaporization of water.

In many cases the vaporization of large masses of water coming in contact with highly-overheated plates is supposed to produce the sudden increase of pressure which is regarded as the cause of the explosion. A large amount of plate raised to a red heat might, no doubt, contain a sufficient quantity of heat to produce this effect; but general experience as well as direct experiment have demonstrated the fact that water thrown on a red-hot plate does not absorb heat with sufficient rapidity to generate suddenly a large quantity of steam. Several experiments were made by the Manchester Steam-users' Association to test this theory. Some small empty boilers were made red hot and water was forced into them, but in every case the boiler failed to explode. In most

boilers the feed-entrance is near the bottom, and when the feed is turned on the water will rise gradually up to the overheated plates and will not be scattered over them. Severe overheating of plates in a boiler frequently opens the riveted seams, and thus offers a means of escape to the steam and prevents an excessive accumulation of pressure.

In nearly every case in which severe overheating of portions of the boiler has taken place previous to an explosion it is reasonable to suppose that the loss of strength in the overheated plates, or their strained condition when suddenly cooled off, would be sufficient to cause rupture even with the ordinary working pressure; and while an increase of pressure produced by the sudden vaporization of a certain quantity of water and a violent projection of water may have occurred simultaneously and to a certain degree intensified the disruptive force, it is the weakened condition of the boiler which must be regarded as the primary cause of the explosion.

Assuming that a boiler explodes either in consequence of a sudden reduction of its strength or of a gradually-accumulated overpressure, rupture commences at the weakest part and continues, following the lines of least resistance, in such parts as have been reduced in strength or are left insufficiently supported after the primary fracture. Detached portions of the boiler are projected with more or less violence, impelled by the unbalanced force of steam pressing on their surfaces, and a force of corresponding magnitude reacts on the opposite walls of the boiler. The steam expands to atmospheric pressure, and a portion of the heated water vaporizes as the superincumbent pressure diminishes. The steam suddenly generated in the body of heated water carries along a mass of water, the impact of which assists in the work of destruction.

The rapidity with which these consecutive effects are produced depends on the nature, location, and extent of the fractures. The weight and temperature of the water and steam determine the amount of energy stored up in a boiler; but the violence of an explosion, or the work done in exploding a boiler, depends greatly on the rapidity with which the energy stored up in a boiler is liberated.

In discussing one of the experimental steam-boiler explosions at Sandy Hook, N. J., in 1871, Professor R. H. Thurston presented the following calculations of the energy stored up in the boiler and of the work done by the liberated forces:

"The steam boiler referred to weighed 40,000 lbs., and contained about 30,000 lbs. of water and 150 lbs. of steam, all of which had a temperature of 301° Fahr., when, at the moment before explosion, the steam-pressure was 53½ pounds above that of the atmosphere.

"When the explosion took place the whole mass at once liberated its heat, until

it had cooled down to the temperature of vapor under the pressure of the atmosphere.

"In this act the water gave off $30,000 \times 89° = 2,670,000$ British thermal units, and the steam lost the difference between its total heat at 301° and that of 212° Fahr., or $150 \times 27.2° = 4,080$ thermal units. The sum $2,670,000 + 4,080 = 2,674,080$ thermal units has an equivalent in mechanical energy of $2,674,080 \times 772 = 2,064,389,760$ foot-pounds, and this was sufficient to have raised the whole boiler and contents, weighing 70,000 lbs., to a height of 29,491.282 feet—*more than five miles.* This represents the *maximum* possible effect.

"The *least* effect would have been produced had the liberation of heat and the production of additional quantities of steam, within the mass of water and at its surface, been so sluggish as to have given no assistance in propelling the fragments of the ruptured boiler, the whole destructive work being done by the simple expansion of the steam which filled the steam-spaces.

"The total amount of mechanical energy set free from the steam alone was $4,080 \times 772 = 3,149,760$ foot-pounds, or sufficient to raise the whole boiler through a space of 78.74 feet and, water included, 44.99 feet. Owing to the greater inertia of the lower part of the boiler, and particularly of its inelastic burden of water, the principal part of this work was undoubtedly performed upon the upper portion and steam-chimney of the boiler, weighing probably 6,000 lbs.; and, if entirely expended in this direction, the work thus done was equivalent to raising this 6,000 lbs. to a height of 525 feet.

"This latter case is capable of treatment in quite a different way from the above. As the boiler was completely torn in pieces, the steam must have expanded pretty equally in all directions, except where checked in its downward movement, and may probably be treated as if forming a rapidly-expanding hemisphere of vapor, its centre being in the steam-space of the boiler.

"The expansion of this hemisphere would have continued until the tension of the steam was reduced to that of the surrounding atmosphere, and would have continued through a mean distance, as given by an approximate estimate, of 4.5 feet. The mean pressure would be 25 pounds above the atmosphere nearly.

"The area of cross-section of the steam-drum was 4,071 square inches, and $4,071 \times 25 \times 4.5 = 457,987.5$ foot-pounds, the amount of work done in its projection.

"The weight of the steam-drum, which was $\frac{1}{4}$ inch thick, 6 feet diameter, and 8 feet 8 inches high, was, with its braces, 2,500 lbs., and $457,987.5 \div 2,500 = 183.2$, the height in feet to which the drum might have been thrown by the simple expansion of the confined steam. In fact, the steam-drum had attached to it, when found after the explo-

sion, a considerable part of the boiler-top, which, being comparatively light and being acted upon by similar pressures, must have considerably accelerated rather than retarded its ascent.

"The actual height of ascent of this piece was variously estimated by the spectators at from 200 to 400 feet." (*Journal of the Franklin Institute, March*, 1872.)

3. Phenomena of Boiler-explosions.—"When a boiler gives way from over-pressure or sudden contraction a rent may be formed or a piece of plate blown out. The former is the most usual manner of yielding; but in both cases it will depend upon the strength, nature, and arrangement of the material bounding the initial fracture, as well as its position, and also upon the pressure, temperature, and amount of water and steam in the boiler, whether the contents will gradually escape through the opening already made, or whether in their violent rush they will increase the extent of opening, and make it easy for the steam behind to tear the boiler into several pieces and cause a violent explosion.

"Now, to make this more clear, we shall first consider the influence of the position of fracture. Many cases have occurred of manhole-lids on the crowns of horizontal boilers being blown aloft either from defect of fastening down or defect of material. When the manhole is properly fortified with a mouth-piece or ring the cover is projected aloft, the contents gradually escape through the hole, and the boiler is left on its seat (if this be sufficiently strong to withstand the recoil), and probably no further damage is done, except to the boiler-house roof. Should, however, the same accident happen to a manhole-cover underneath the boiler, placed near the ground, the effect will be very different, and it will depend upon the weight of the boiler and water contained, size of manhole, pressure of steam, and distance of aperture from the ground whether the boiler and its contents will be merely raised a little from its seat, or whether it will be shot aloft like a rocket by the unbalanced pressure on the discharge of steam. If the manhole were in the side of a vertical boiler, and near the top, the blowing-off of the lid into an open space in front would probably topple over the boiler if it were not well supported.

"Again, if the manhole in our first case were without any provision for strengthening the plate surrounding it, and if the edges of the plate were reduced in strength by fractures or by corrosion and wear, the rush of steam and water on the lid blowing off would probably start a rent in the shell, which a high pressure within the boiler would continue along the lines of least resistance, and the result would be a violent explosion, the severed plates being carried in different directions.

"The remarks respecting the blowing-away of the manhole-cover apply also to the case of a piece of plate being blown out." (*Wilson.*)

When a single stay gives way in a boiler there is a strong probability that the adjoining stays will also give way in rapid succession on account of the greatly-increased load thrown on them. The unsupported plate bulges out and finally tears, usually through the line of rivet-holes in the seams. Unless braces are much reduced in sectional area by corrosion, their weakest part is generally at the weld or in their fastenings. The angle-irons to which braces are attached tear frequently through the rivet or bolt holes. When the bulging of plates exceeds a certain limit the stay-bolts are drawn through them, especially when they are simply screwed in or secured by riveted heads.

When large flues collapse without fracturing to a great extent the steam or water issuing through the cracks or opened seams may reduce the pressure, or, by putting out the fires, check the increase of pressure sufficiently to avert an explosion. If the fracture is of larger extent there is great danger of scalding by hot water and steam; the furnace-doors will be blown open and the fire scattered over the fire-room floor. If a flue is ruptured to such an extent that it no longer acts as an efficient stay for the plates to which it is attached, a violent explosion will be the probable result, the ends of the boiler being blown away in opposite directions.

Similar results will be produced when a number of tubes are either fractured or pulled out of the tube-plates.

The reaction of the steam and water issuing from the collapsed furnace-crown of a locomotive boiler or of a vertical fire-tube boiler frequently sends the boiler into the air to a great height like a rocket.

An extensive rupture in a cylindrical boiler generally results in a violent explosion and the total destruction of the boiler, because its various parts are connected in such a manner as to form essential supports for each other. On the contrary, large portions of the flat stayed surfaces of a rectangular boiler may give way without seriously weakening the rest of the boiler.

The violent explosion of the large rectangular boiler of the British armored vessel *Thunderer*, in 1876, commenced with the giving-way of some stay-bolts which tied the boiler-front to the uptake. The whole front above the smoke-connections was torn off the shell through the lines of rivet-holes in the seams and thrown down, and the portion of the uptake to which the front was stayed was torn and bent out of shape; but the rest of the boiler was uninjured.

The reports and papers published by the Hartford Steam-boiler Inspection and In-

surance Company contain descriptions and illustrations of several instructive cases of explosion of locomotive and marine boilers, in which the semi-cylindrical top gave way, rupture commencing at and following a line of grooving near the horizontal seams. In one case the whole semi-cylindrical top was blown off, fracture taking place almost simultaneously at both sides through lines of grooving near the horizontal seams which joined the top to the lower rectangular part of the shell, and extending through the transverse seams connecting the top to the front plate and to the cylindrical barrel of the boiler.

In other cases a piece, extending nearly the whole length of the semi-cylindrical top, was torn off on one side of the boiler. The fracture followed likewise a line of horizontal grooving near a seam, and extended in a transverse direction to lines where the shell was strengthened by stays or by the flanges of steam-domes, the detached pieces bending over on these lines as on hinges. In one case the piece thus torn off the side of a locomotive boiler was about 5½ feet long and 1½ feet wide, and had an area of nearly 7½ square feet. The pressure on this area was but a little less than 70 tons at the pressure of 130 pounds per square inch. The reaction of the force set free by the rupture overturned the locomotive.

When a cylindrical shell gives way at a longitudinal seam, or by tearing through a longitudinal line of weakness produced by corrosion or grooving, the fracture may be confined to a single plate, and, by continuing through the circumferential seams, detach the belt of which it forms part from the shell, or the longitudinal fracture may continue through several belts. The latter is generally the case when the longitudinal seams of adjoining plates are in the same line. When they break joint the rent extends sometimes in a diagonal direction through adjoining plates till it strikes again a longitudinal seam, along which it continues. As the fracture extends in a transverse direction after the longitudinal rupture has taken place, the cylindrical plates are flattened out, and in this manner the rivet-heads in circumferential seams are frequently torn off. When the longitudinal rupture takes place near the bottom of the boiler the detached plates will probably be thrown some distance ; but when this line of fracture is near the top the plates may be found in nearly their original location. There is a strong probability that when a circumferential belt of plates has been torn off a cylindrical shell, the two ends of the boiler will separate and will be thrown a greater or less distance in opposite directions. But in some cases, when the two ends are tied together strongly by their braces, stays, and flues, or when the destructive forces spend themselves promptly through the vent made by the original fracture, the boiler remains otherwise uninjured and is not moved from its seat.

In the case of the boiler-explosion on the steamer *Westfield*, in the harbor of New York, in 1871, rupture commenced at one side of the cylindrical shell of the boiler along a horizontal line of grooving. The fracture extended through the width of one plate and continued through the transverse seams, detaching one belt from the rest of the shell and flattening it out. This portion of the shell was found lying directly opposite the original position in the boiler before the explosion. The front and the back of the boiler had separated and were thrown some distance in opposite directions.

4. Investigation of Boiler-explosions.—"In investigating the cause of a complicated explosion the relative weights, positions, shapes of the scattered pieces, and the direction taken by them must first of all be carefully noted, and their original positions in the boiler be assigned to them, along with the positions of the different mountings, manner of staying, and absence or presence of means for strengthening domeholes, manholes, tubes, combustion-chambers, etc. The original shape of the shell and large flue-tubes should be ascertained as accurately as possible. The primary rent is then to be sought for. In many cases the direction taken by the heavier pieces is a guide to this, as the fractured plates, if free to move, will shoot off, the light pieces along with and in the direction of the first rush of steam, and the heavier pieces in an opposite direction.

"That this, however, is not always the case is obvious; as, for instance, when the boiler turns over before separating, or where the direction a piece of the shell would take, if free to move, is changed by part of it clinging for a time to the larger mass to which it may be attached.

"All the edges of the plates and angle-irons along the lines of fracture should be carefully examined in search of weak places, such as thinness caused by grooving and corrosion, external and internal, wasting of rivet-heads, defective rivet-holes, insufficient lap, old flaws and fractures, patching and other signs of repair, indications of softening or deterioration by overheating, condition of low-water indicating apparatus, safety-valves, and pressure-gauges.

"A close examination of the shape of the rivet-heads and of the shapes and sizes of the plates and arrangement of seams throughout the boiler will usually lead to detection of repairs when these are not obvious at first sight. The color and nature of the fractures, and whether they be short or jagged, are the only guides to the length of time they have existed and how they are produced.

"Overheating from shortness of water usually declares itself by the bulging and buckling of the plates, by breaking off the incrustation on one side, and by producing a burnt appearance, along with removal of soot, etc., on the other side, by the starting

of joints and melting of fusible plugs, and in furnace-tubes also by forming corrugations parallel with the ring-seams. These corrugations are produced by the excessive expansion of the plates at the part where they occur. . . .

"One or more of the defects above indicated will in most cases be found to be the cause of explosion, which may have occurred at the ordinary working pressure. But if no such defects can be found, and the calculated strength of the boiler be sufficient for the alleged working or blowing-off pressure, the condition of the safety-valves, levers, weights, springs, double-eyes, pipes, or branches must be still more closely enquired into and the strength of the plates at fractures carefully tested. The alleged blowing-off pressure must be carefully checked by calculating the weight upon the valve, and the accuracy of the pressure-gauge as well as its condition should be ascertained, and anything else suggested by the nature of the case that may throw light upon the manner in which the overpressure has been brought about." (*Wilson.*)

5. Experimental Steam-boiler Explosions.—A series of instructive experiments on the explosion of steam boilers was made by the United Railroad companies of New Jersey, under the direction of Francis B. Stevens, at Sandy Hook, N. J., in November, 1871, in the presence of a number of prominent engineers.

The first experiment was made with a boiler of the type represented in figure 2, Plate XXI. It was 28 feet long, and the cylindrical portion of the shell was 6 feet 6 inches in diameter and of iron a full quarter-inch thick. The boiler had been thirteen years in use, and the last inspector's certificate had allowed 40 pounds of steam to be carried in it. Before the final trial it had been repaired and tested by hydrostatic pressure to 82 pounds per square inch without fracture, and then had been subjected to a steam-pressure of 60 pounds per square inch without fracture.

On its final trial a heavy wood-fire was built in the furnaces, the water standing 12 inches deep over the flues. The pressure rose rapidly until it reached 90 pounds, when leaks appeared in all parts of the boiler, and at 93 pounds a rent at the rear of the steam-drum, where it joined the shell, became so great that the steam passed off more rapidly than it was formed. After the fires were extinguished it was found that at the point where the steam-drum joins the shell the latter had been drawn downwards, and each crown-sheet, originally flat and stayed to the roof of the shell, had been forced down and bulged, to an extent of about 2 inches, between two rows of the stays referred to, pulling the outside shell with it away from the lower sheet of the vertical steam-drum, thus opening a seam, venting the boiler, and preventing an explosion.

The second experiment was made on a flat rectangular box, 6 feet long, 4 feet high, and 4 inches wide over all, made to represent the water-leg of a boiler. The two side-

plates were of the best flange fire-box iron, $\frac{5}{16}$ inch thick. They were held together by a single row of rivets at their edges, passing through a frame made of wrought-iron bars $3\frac{3}{8}$ inches wide and 2 inches deep, mitred at their ends. The side-plates were braced together every $8\frac{3}{4}$ inches one way and $9\frac{3}{16}$ inches the other way of their surfaces by screw stay-bolts of $1\frac{1}{8}$ inches diameter with their ends slightly riveted over. This box had been subjected to a hydrostatic pressure of 138 pounds per square inch without fracture, and to a steam-pressure of 102 pounds per square inch.

This box was set on one edge between walls of brick masonry, and it was filled with water up to about five-sixths of its height; a strip at the top of the box about 15 inches wide projected beyond the masonry. The enclosed portion of the box was heated by two small furnaces in which wood-fires were built. The pressure rose in 33 minutes from 0 to 165 pounds per square inch.

"When the pressure reached 165 pounds to the square inch the box exploded with a loud report, completely demolishing the brickwork by which it was enclosed. The two sides were hurled in exactly opposite directions, and to about equal distances, at right angles to their surfaces. The fracture had occurred in one plate only, and was along the whole riveted seam joining it to the frame. For a large part of the length of the seam this plate was torn out between the rivets, and for the remaining part the rivets were sheared. The other plate was not fractured nor were the bars of the frame broken; the plate and the frame remained riveted together, but not uninjured, all the bars of the latter being bent considerably inwards, forming an irregular curve of from four to six inches versed-sine. Both plates were bulged out irregularly, so as to be about nine inches dishing, and the bulging took place near the bars. Not one of the bolts was broken, and neither the threads upon their ends nor the threads in the plate were stripped or injured, but the slight riveting-over of the ends of the bolts was broken off in all of them." . . . "Between the bolts there was a small permanent stretching of the plates, giving each space between the bolts a slightly dishing or bulged form in addition to the general bulging of the plates, thus forming a system of secondary bulges, as it were, and around every bolt both plates were strongly marked by a congeries of circular crispations." (*See 'Report of United States Naval Engineers' and Journal of the Franklin Institute*, 1872, *Nos.* 1 *and* 2.)

The following account of the third experiment is taken from the report of the board of United States naval engineers, consisting of B. F. Isherwood, E. S. De Luce, and Sidney Albert, Chief Engineers United States Navy, detailed by the Secretary of the Navy to witness these experiments:

"The boiler that was exploded during this experiment was built by T. F. Secor in

1845, and taken out of the steamboat *Bordentown* in August last, after having been 25 years in use. When taken out the inspector's certificate allowed it to be worked with a pressure of 30 pounds per square inch. It was a horizontal fire-tube boiler, with the tubes returned immediately above the furnace and combustion-chamber.

"It had but one furnace, and that was 11 feet 5 inches in width, with grate-bars 7 feet in length. The top of the furnace and the top of the combustion-chamber were flat, and braced to the flat top of the shell above them by rectangular braces 2 inches by ½ inch in cross-section, placed 17 inches apart crosswise the boiler and 12 inches apart lengthwise the boiler, each brace holding a flat surface of 204 square inches, to which it was attached by crow-feet so arranged that the flat surface between the sustaining rivets was 12 inches square. The flat water-spaces were braced, at intervals of 8 inches in one direction and 12 inches in the other, by 1-inch diameter screw-bolts, each of which held a flat surface of 96 square inches. The iron plates of the boiler were a large ¼ inch thick. . . .

"The shell of the boiler was rectangular, with the exception that the vertical sides were joined to the flat top by quadrantal arcs of 37 inches radius. All the seams were single-riveted. Upon the centre of the top of the boiler was a cylindrical steam-drum of 6 feet diameter and 8 feet 8 inches height. The flat water-space at the front of the furnace was 4½ inches wide, and that at the back end of the boiler was 5 inches wide, including thicknesses of metal. The width of the boiler was 12 feet 2 inches, its length 15 feet 5 inches, and its height, exclusive of the steam-drum, was 8 feet 6 inches.

"The shell was braced very unequally. Each upper brace, 1⅛ inches large in diameter, sustained the pressure upon a surface 28 by 12 inches, or 336 square inches; and each rectangular vertical brace adjacent to the sides, 2 inches by ½ inch cross-section, sustained the pressure upon a surface 19 by 12 inches, or 228 square inches; these were the weakest places.

"The following were the grate and the water-heating surfaces of the boiler:

Grate-surface	$79\frac{1}{12}$	sq. feet.
Heating-surface in furnace	180	"
" " in combustion-chamber and back-connection	103	"
" " in tubes	2,171	"
" " in uptake	64	"
Total heating-surface	2,518	"

"On the 2d of September last this boiler was subjected to a hydrostatic pressure of 60 pounds per square inch, when twelve crow-feet gave way. After being repaired it was again subjected on the 4th of November last, when erected at Sandy Hook, to a hydrostatic pressure of 59 pounds per square inch, which it bore without fracture; and on the 16th of November last it was subjected to a steam-pressure of 45 pounds per square inch, which it also sustained without fracture.

"The fuel used in the experiment was wood, and the water-level in the boiler was 15 inches above the highest point of the tubes. When the fire had been brought to steady action the pressure of the steam gradually increased at the following rate, commencing with the pressure of 29½ pounds per square inch:

Time P.M.		Steam-pressure in pounds per square inch above atmosphere.	Time P.M.		Steam-pressure in pounds per square inch above atmosphere.
Hours.	Minutes.		Hours.	Minutes.	
12	21	29½	12	30	46½
12	23	33½	12	31	48½
12	25	37½	12	32	50
12	27	41	12	33	52
12	29	44½	12	34	53½

"At the pressure of 50 pounds per square inch some of the braces in the boiler gave way with a loud report, and when the pressure of 53½ pounds was reached the boiler exploded with terrific violence. The steam-drum and a portion of the shell attached to it, forming a mass of about three tons weight, were hurled to a great height in the air and fell to the earth at about 450 feet from the original position of the boiler, crushing several trees in their fall. Two other large fragments fell at less distances, while smaller ones were thrown much farther. Almost the whole of the boiler was literally torn into shreds, which were scattered far and wide, the only portion remaining where the boiler had been being the tubes. These, though considerably distorted, were otherwise uninjured. Both tube-plates had been blown from the tubes in opposite directions and at the same moment, for nearly all the tubes were found lying in a heap on the ground immediately beneath the place they had occupied in the boiler, the riveting of their ends over the plates having been simultaneously stripped. The top of the furnace and the top of the combustion-chamber, which in the boiler were immediately beneath the tubes, had entirely disappeared into *débris*, as had also the sides and ends of the shell. The boiler seems to have first yielded by the fracture of the upper row of horizontal braces. The loud report heard when the pressure attained 50 pounds per square inch was probably caused by their breaking. The larger masses were all thrown in one direc-

tion at right angles to the side of the boiler, but the smaller fragments were projected radially in all directions as from a centre. Two heavy bomb-proofs, constructed of large timbers and sand for the protection of the other boilers, were dislodged, and a part of the fence of the enclosure was destroyed by the impact of the flying fragments. The crow-feet in most cases remained firmly attached to the shell, and the braces had parted, probably in the welds, leaving the ends still secured to the crow-feet. The screw-bolts which braced the flat water-spaces had slipped from their fastenings in the plate without injury to the screw-threads either upon them or in the plate. The latter was permanently bulged or dished between the bolts, and this stretching of the metal had, by its enlargement of the holes, allowed the screw-ends of the bolts to draw out without injury to the threads either on the bolts or in the plates.

"The ground beneath, and for a considerable distance around where the boiler stood, was saturated with the water of the boiler—in fact, made into mud—and the adjacent grass and small shrubbery were so drenched that an ordinary boot was wet through by walking among them. At seven minutes before the explosion took place the water-gauge on the boiler was examined and found to indicate the water-level 15 inches above the top of the tubes.

"The conclusions to be drawn from this experiment are the following:

"*First.* An old boiler, containing a large mass of water above the highest point of its heating-surface, can be exploded with such complete destruction as to reduce it into mere *débris*, and hurl the fragments in all directions with a force that no ordinary construction of building or vessel could withstand.

"*Second.* That the pressure required for so devastating an explosion is the very moderate one of 53½ pounds per square inch.

"*Third.* That with only a wood-fire, generating a far less quantity of heat in equal time than a coal-fire, there were required only 13 minutes to raise the pressure from the inspector's working allowance of 30 pounds per square inch to the exploding pressure of 53½ pounds per square inch, showing that a few minutes' absence or neglect of the engineer, coupled with an overloaded or inoperative safety-valve, are all that are needed to produce the most destructive steam-boiler explosion, even with an old and unequally-braced boiler, in which it might be supposed a rupture of the weakest part would precede other fracture, and allow the escape of the pressure without doing further injury.

"*Fourth.* That in accounting for either the fact of an explosion or for its destructive effects there is no necessity for hypotheses of low water, enormous pressures, instantaneous generations of immense quantities of steam, superheated steam, the formation of hypothetical gases, development of electricity, etc., etc. The most frightful catas-

trophe can be produced by simply gradually accumulating pressure of saturated steam to a strain at which the strength of the boiler yields, nor need that pressure be much above what is ordinarily employed with boilers of this type.

"*Fifth.* That there is no flashing of boiler-water into steam at the moment of an explosion. On the contrary, with the exception of the small portion of this water vaporized (after the reduction of the pressure owing to the rupture of the boiler) by the contained heat in it between that due to the temperature of the steams of the exploding pressure and of the atmospheric pressure, it remains unchanged, and is thrown around, drenching the objects near it and scalding whomever it falls upon.

"*Sixth.* The weakest portion of the boiler-braces was in their welds.

"*Seventh.* The equal stretching in all directions of the boiler-plates between the screw-bolts, due to their bulging under the pressure, was sufficient to permit the slipping out of the bolts without injury to the screw-threads either upon them or in the plates.

"*Eighth.* That this experiment has conclusively disposed of several theories of steam-boiler explosion, replacing vague conjecture and crude hypothesis with exact experimental facts, and, by thus narrowing the field for the search of truth, has made the discovery more probable."

INDEX.

RODMAN'S TESTING MACHINE
AT
WASHINGTON NAVY YARD.

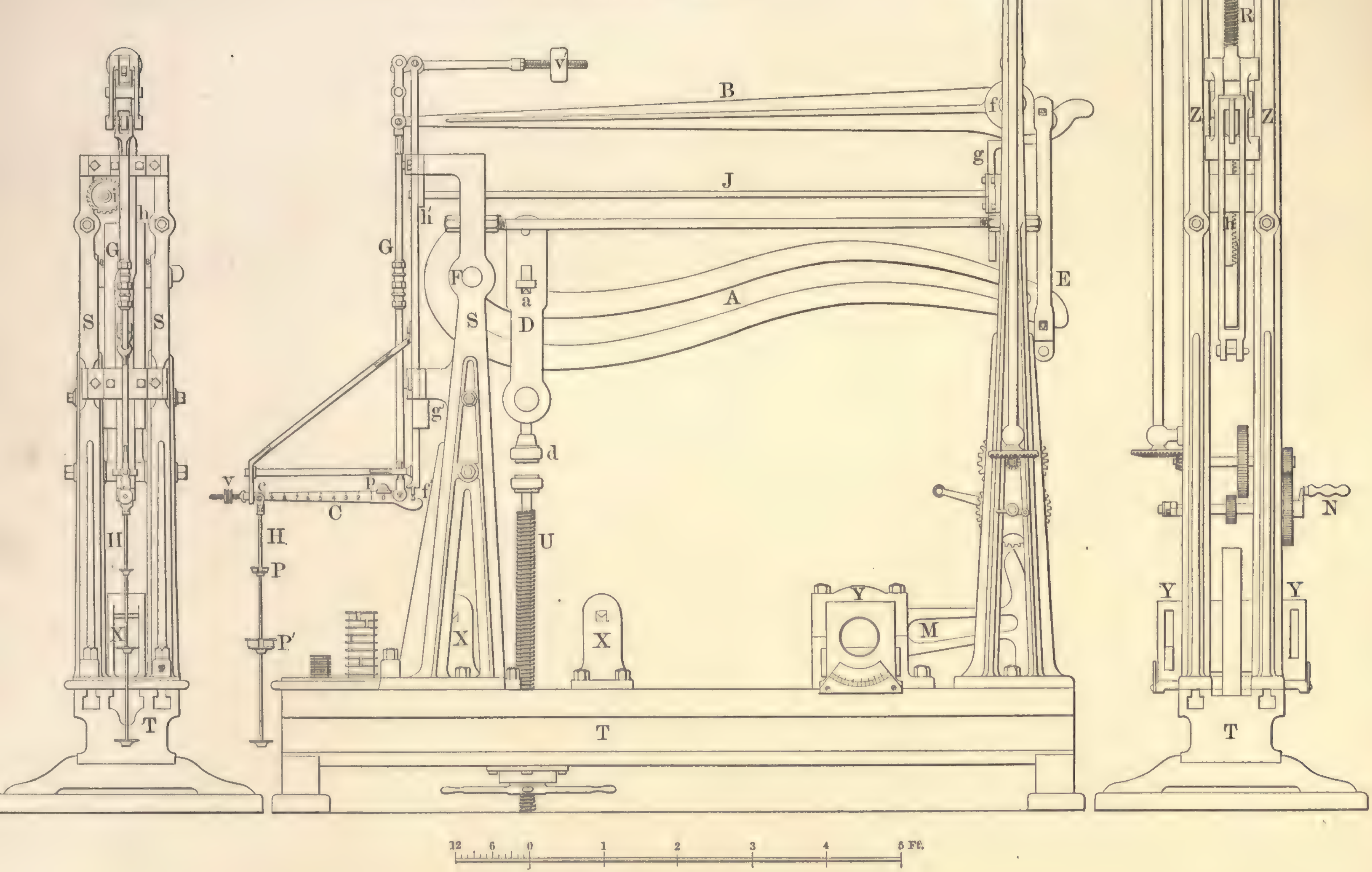
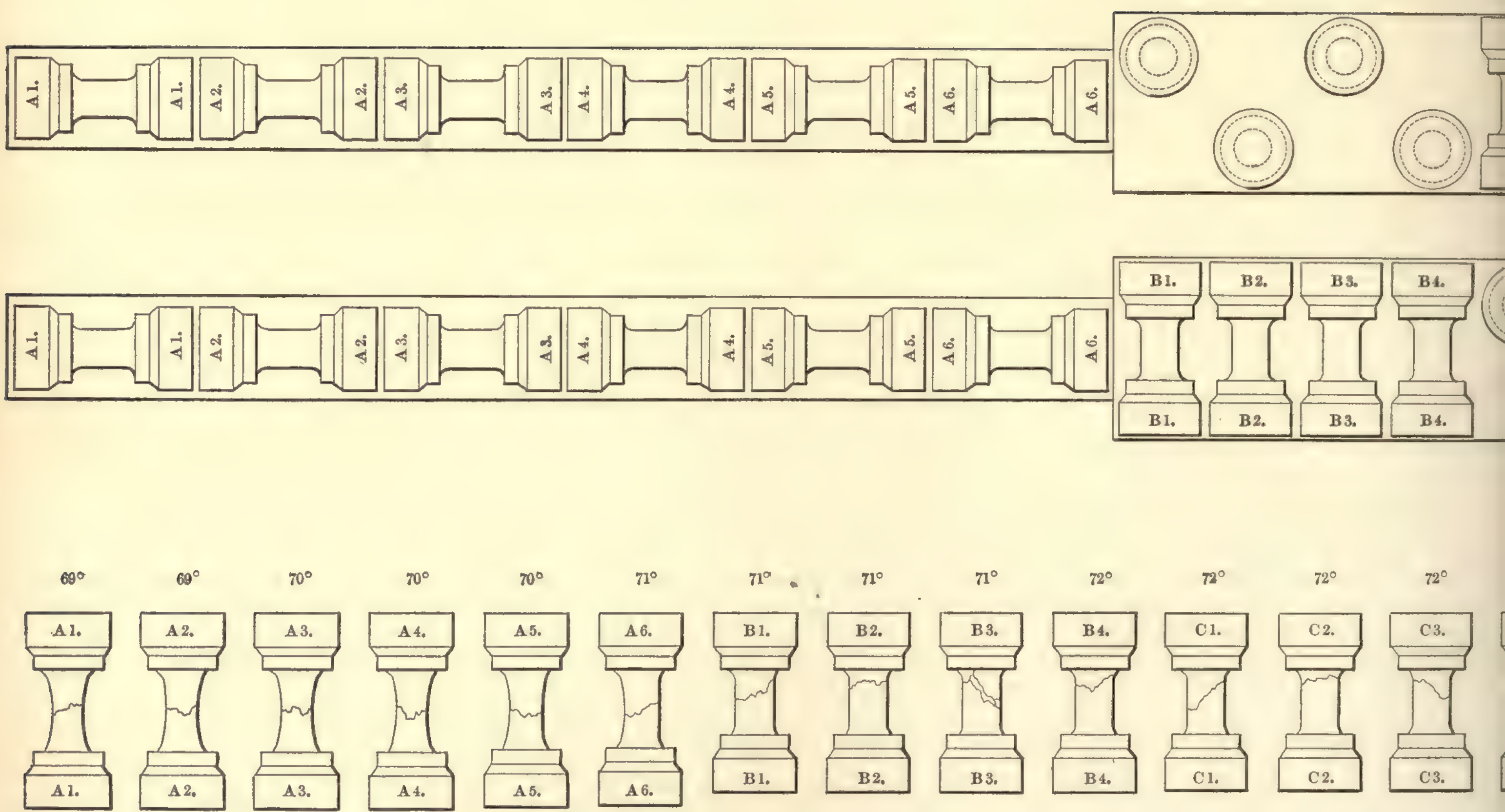


Plate I.

Experiments on Tens

Conducted at th

Chief Engi

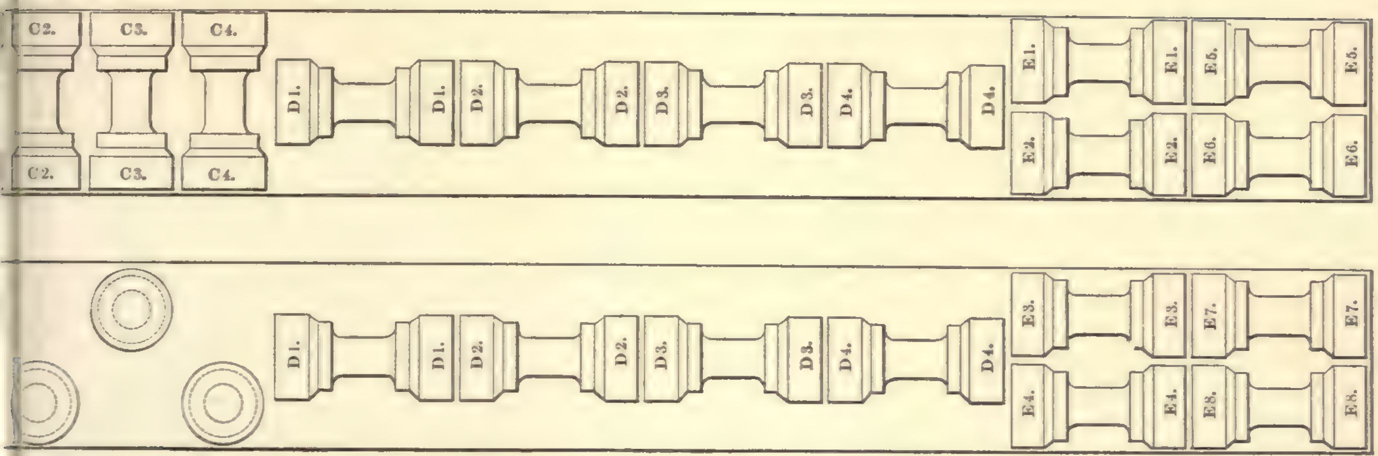


0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798
0.625	0.648	0.629	0.620	0.634	0.778	0.798	0.798	0.798	0.798	0.798	0.798	0.798
0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
0.307	0.330	0.311	0.302	0.316	0.475	0.500	0.500	0.500	0.500	0.500	0.500	0.500
3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875
4.285	4.284	4.275	4.302	4.250	4.190	3.875	3.875	3.875	3.875	3.875	3.875	3.875
0.410	0.409	0.400	0.427	0.375	0.315							
27100	27000	26500	26600	26450	28050	10000	20450	14000	18000	10250	16850	13175
54200	54000	53000	53200	52900	56100	20000	40900	28000	36000	20500	33700	26350
53900						31225				29137.5		

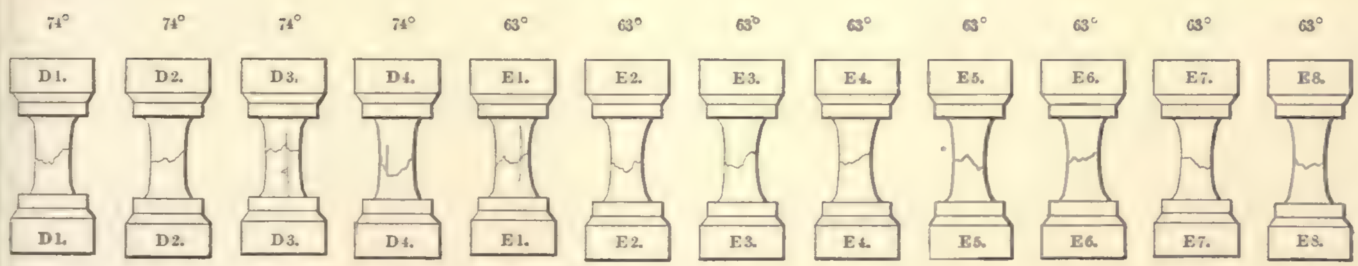
...ngth of Wrought Iron.
...ington Navy Yard,
by
...s. Shock U. S. N.

Plate II.

SKETCH OF SPECIMENS BEFORE TESTING.



SKETCH OF SPECIMENS AFTER TESTING.



0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	0.798	DIAMETER BEFORE TESTING.
0.775	0.750	0.770	0.745	0.650	0.640	0.635	0.616	0.643	0.625	0.627	0.625	DIAMETER AFTER TESTING.
0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500	AREA OF SECTION BEFORE TESTING.
0.472	0.442	0.466	0.436	0.332	0.322	0.317	0.298	0.325	0.307	0.309	0.307	AREA OF SECTION AFTER TESTING.
3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	3.875	LENGTH BEFORE TESTING.
4.175	4.265	4.205	4.265	4.200	4.290	4.290	4.290	4.300	4.290	4.265	4.349	LENGTH AFTER TESTING.
0.300	0.390	0.330	0.390	0.325	0.415	0.415	0.415	0.425	0.415	0.390	0.474	ELONGATION.
25750	25300	25300	25700	26200	26200	26000	25900	26500	25700	25950	26000	ABSOLUTE BREAKING STRAIN
51500	50600	50600	51400	52400	52400	52000	51800	53000	51400	51900	52000	BREAKING STRAIN PER SQUARE INCH.
51025				52112.5								AVER. BREAK, STRAIN PER SQUARE INCH.

RUSSELL & STRUTHERS, ENG'S, N.Y.

Plate III.

Fig. 1.

BOILER FOR U. S. S. "DAYLIGHT."

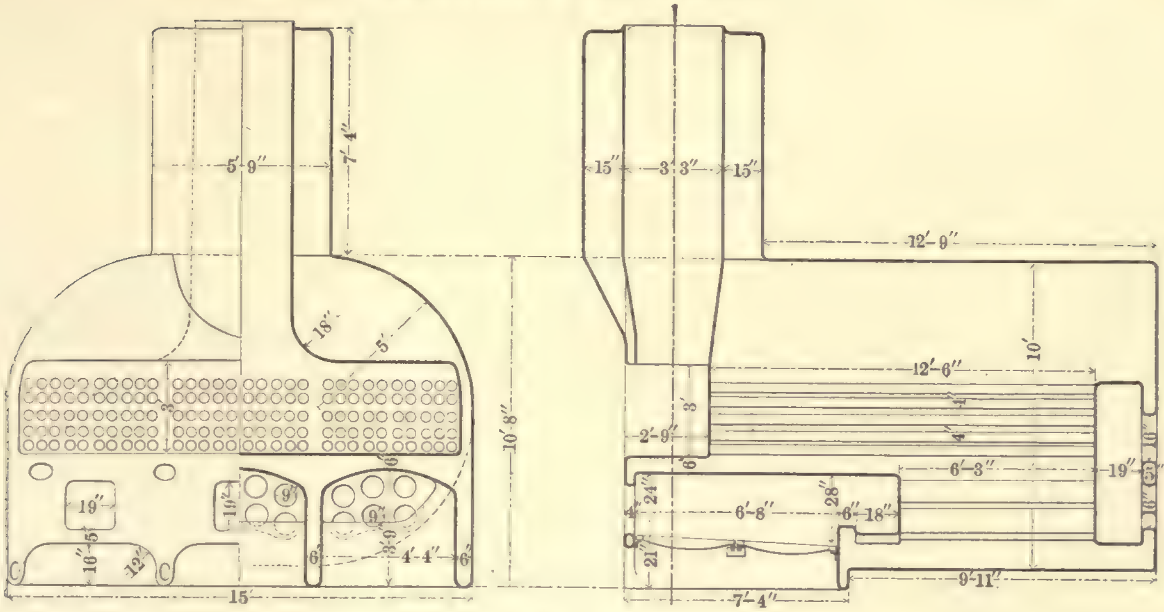


Fig. 2.

TWO BOILERS FOR U. S. S. "KANSAS."

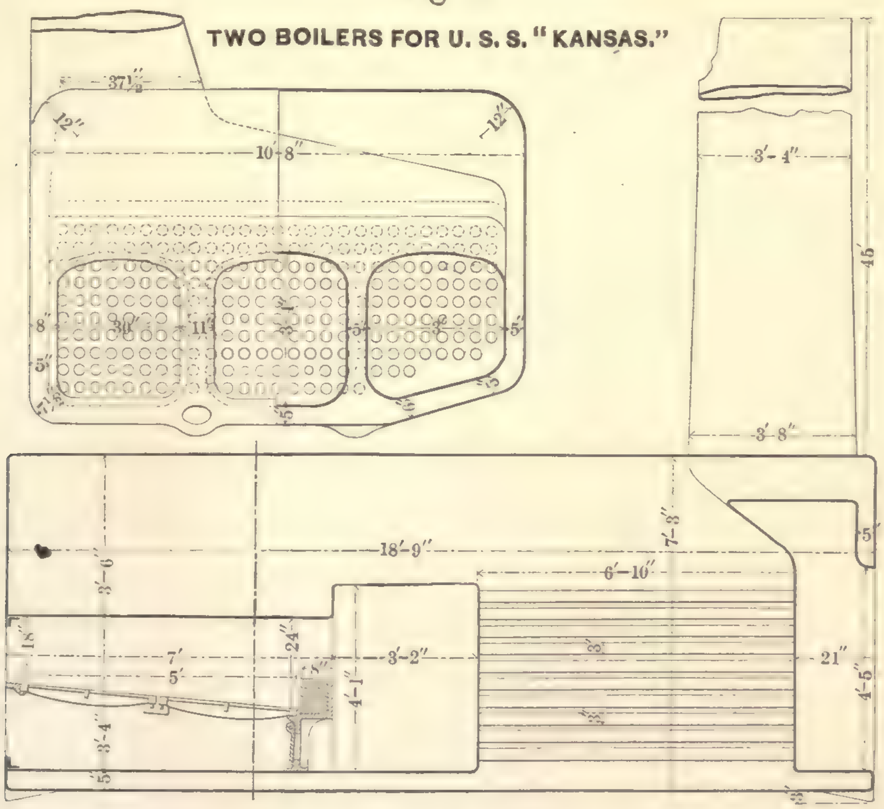
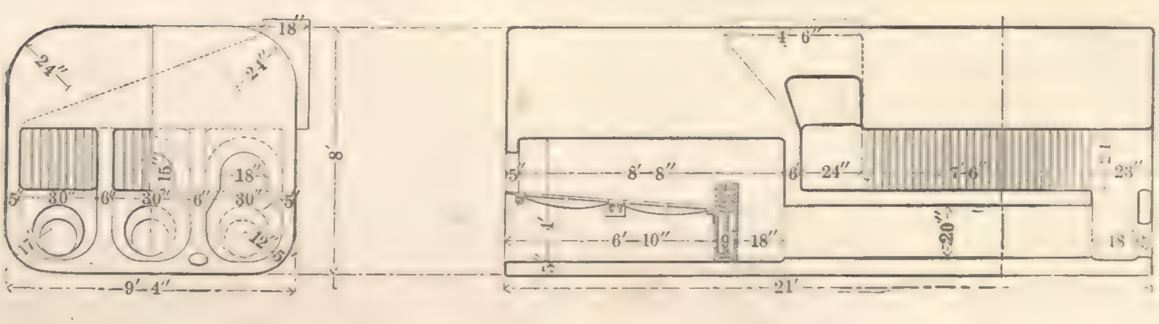
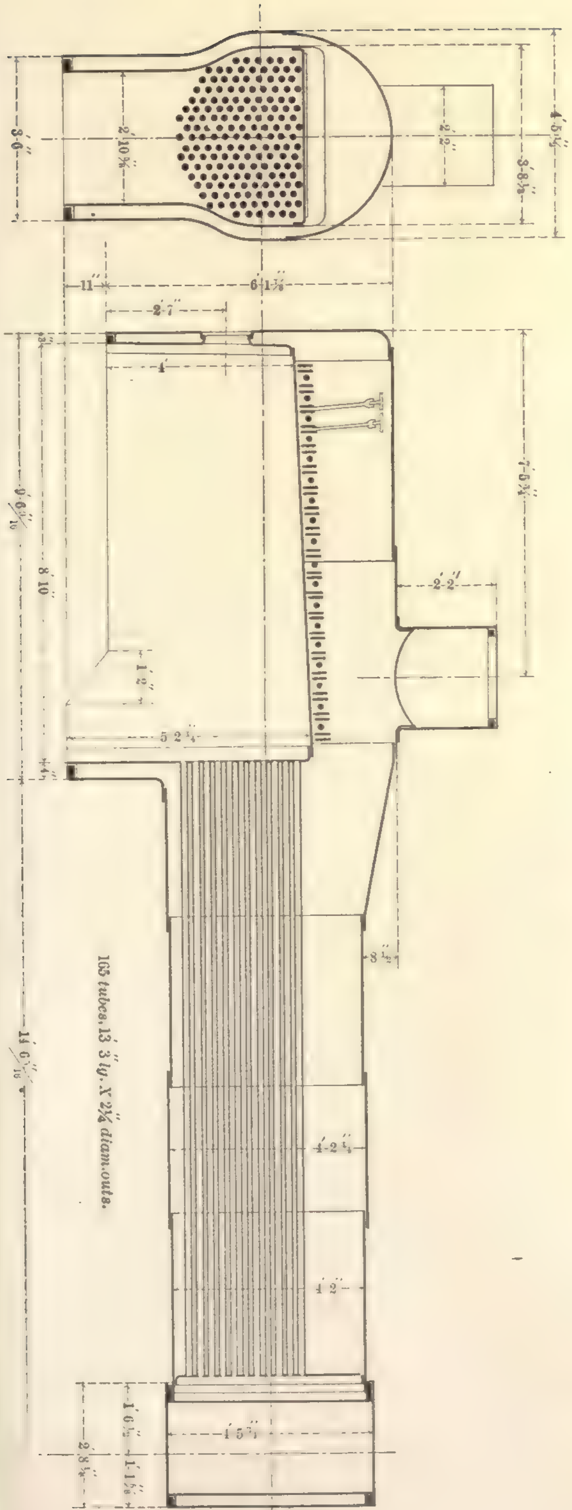


Fig. 3.

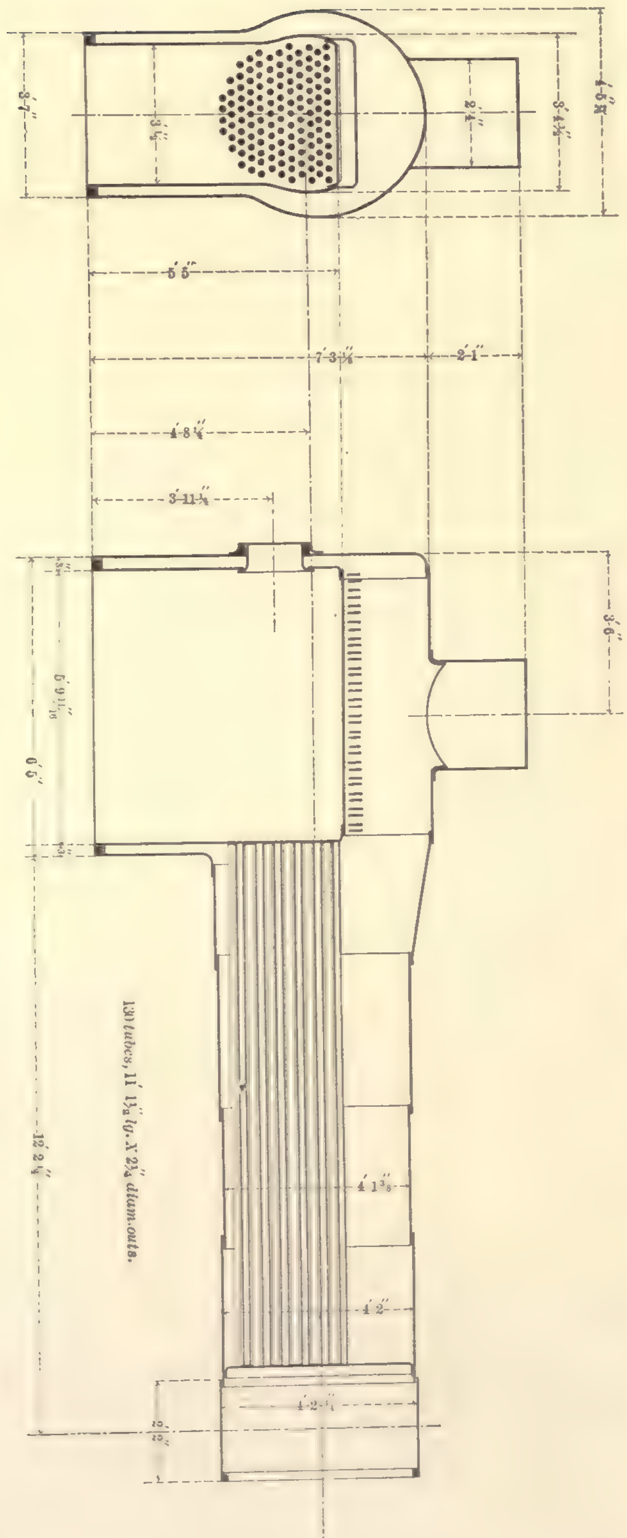
TWO BOILERS FOR U. S. S. "MAHASKA."



Plates IV. & V.



CONSOLIDATION FREIGHT LOCOMOTIVE.



PASSENGER LOCOMOTIVE.

Section G.-H.

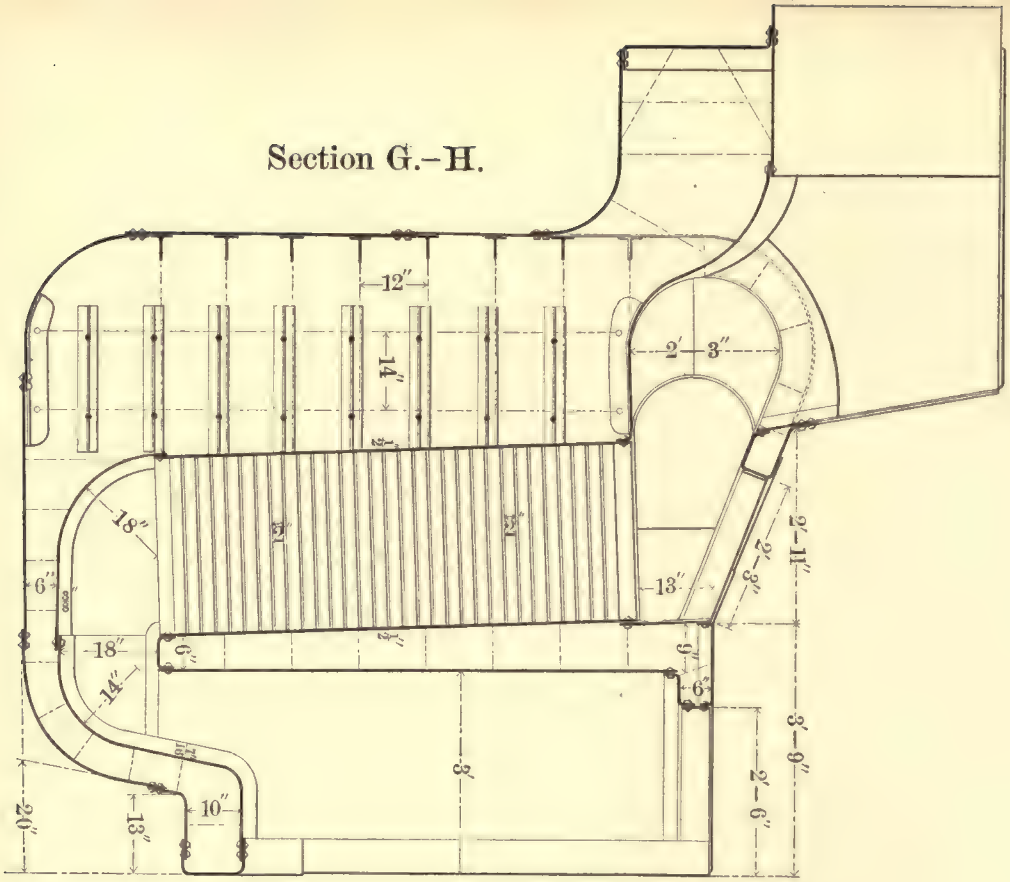
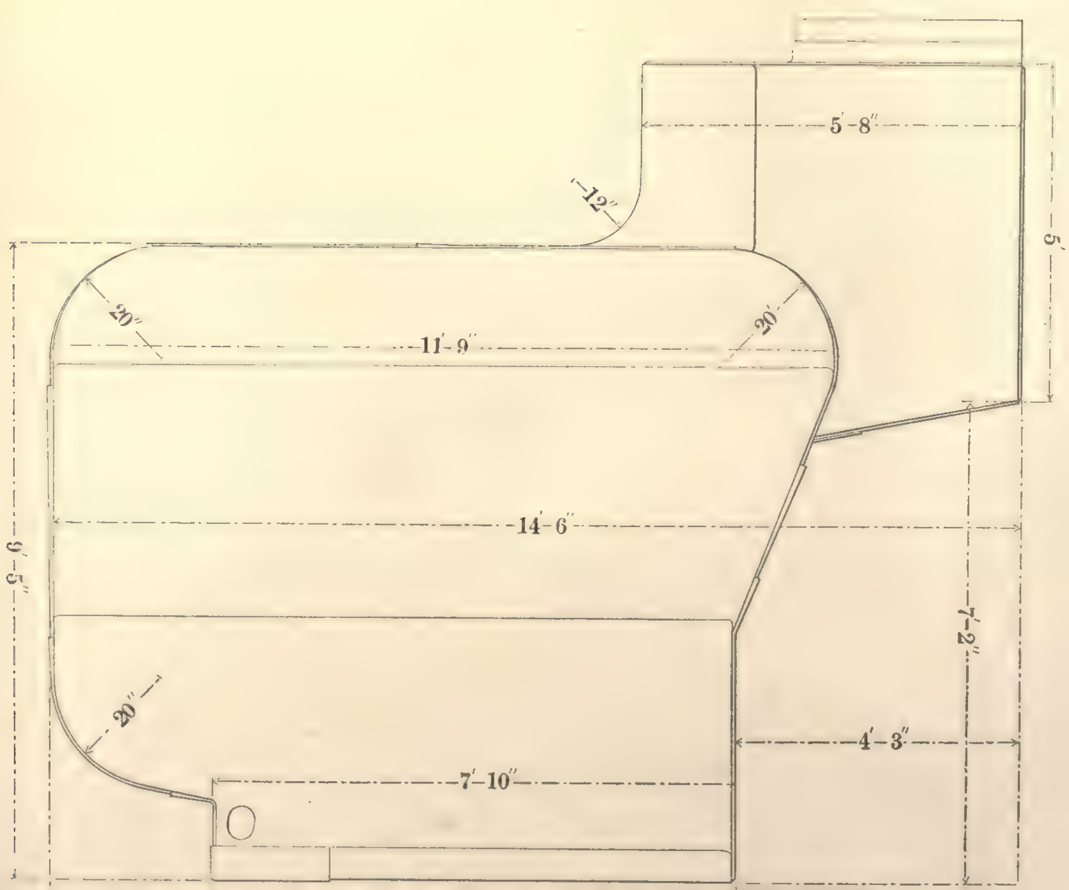


Plate VI.

BOILER FOR U. S. S. "LACKAWAN

Scale: 12 6 0 1 2 3 4 5 6 7 F



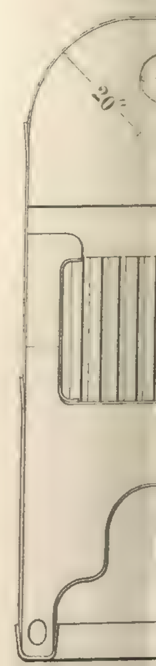
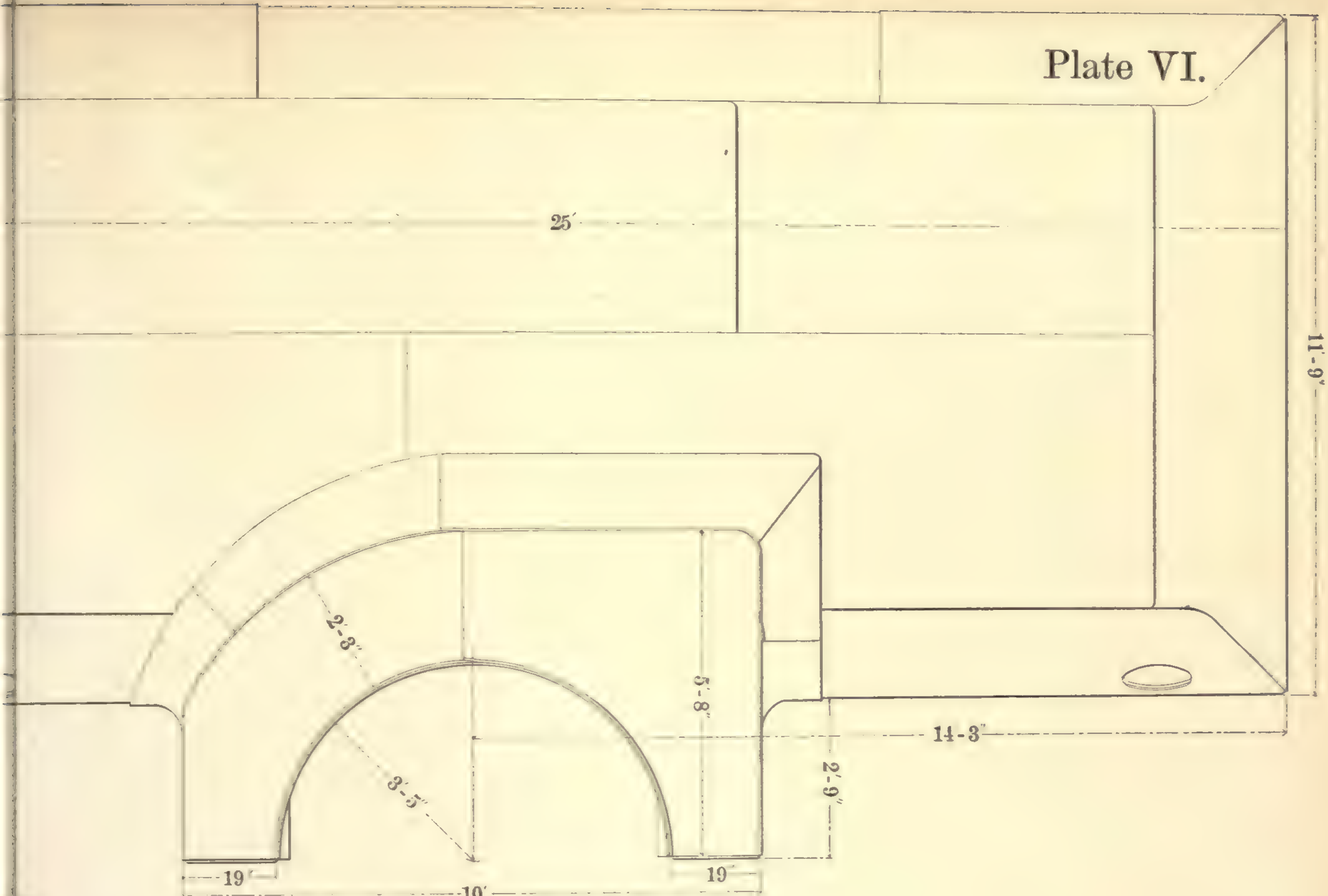
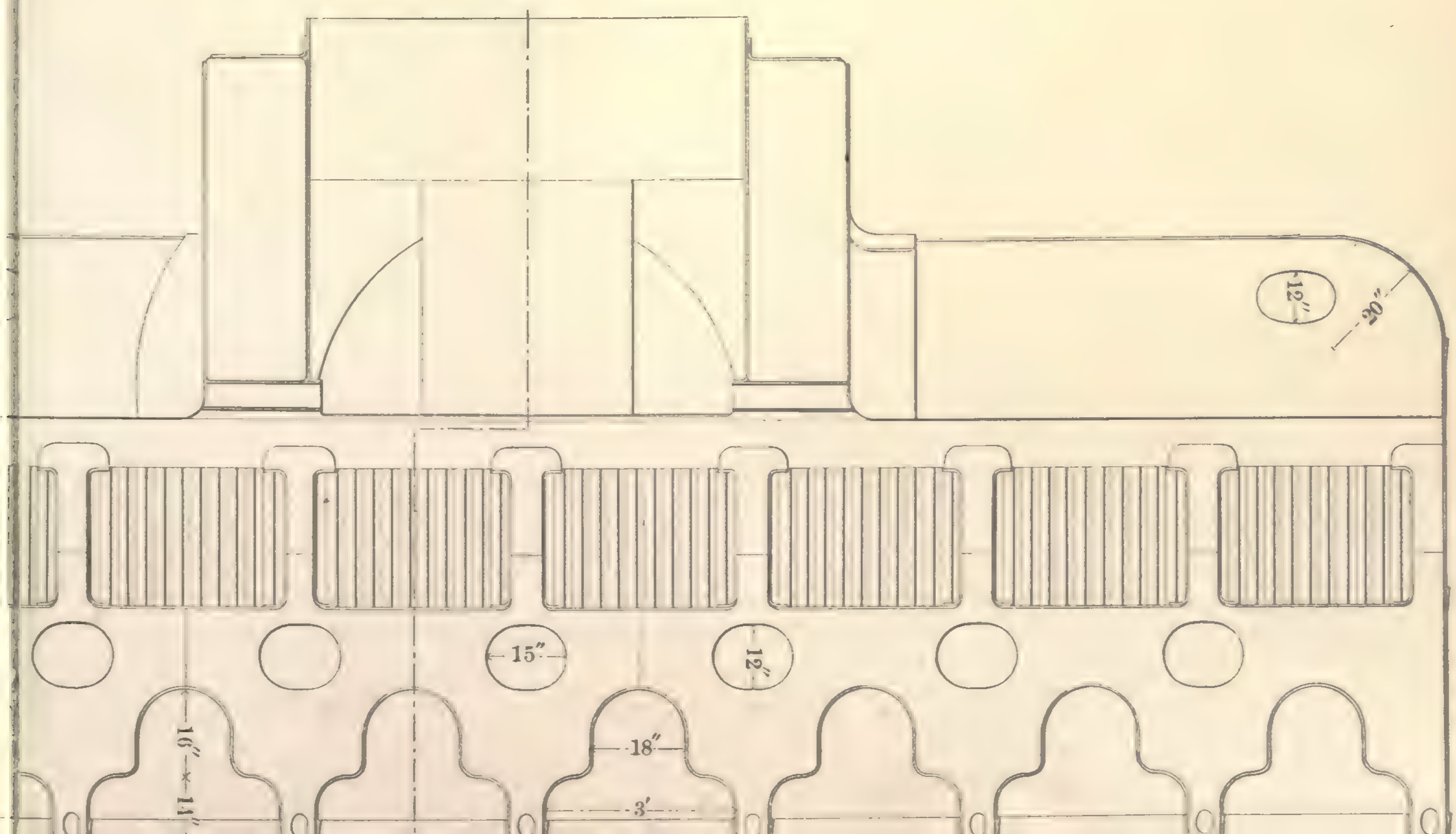
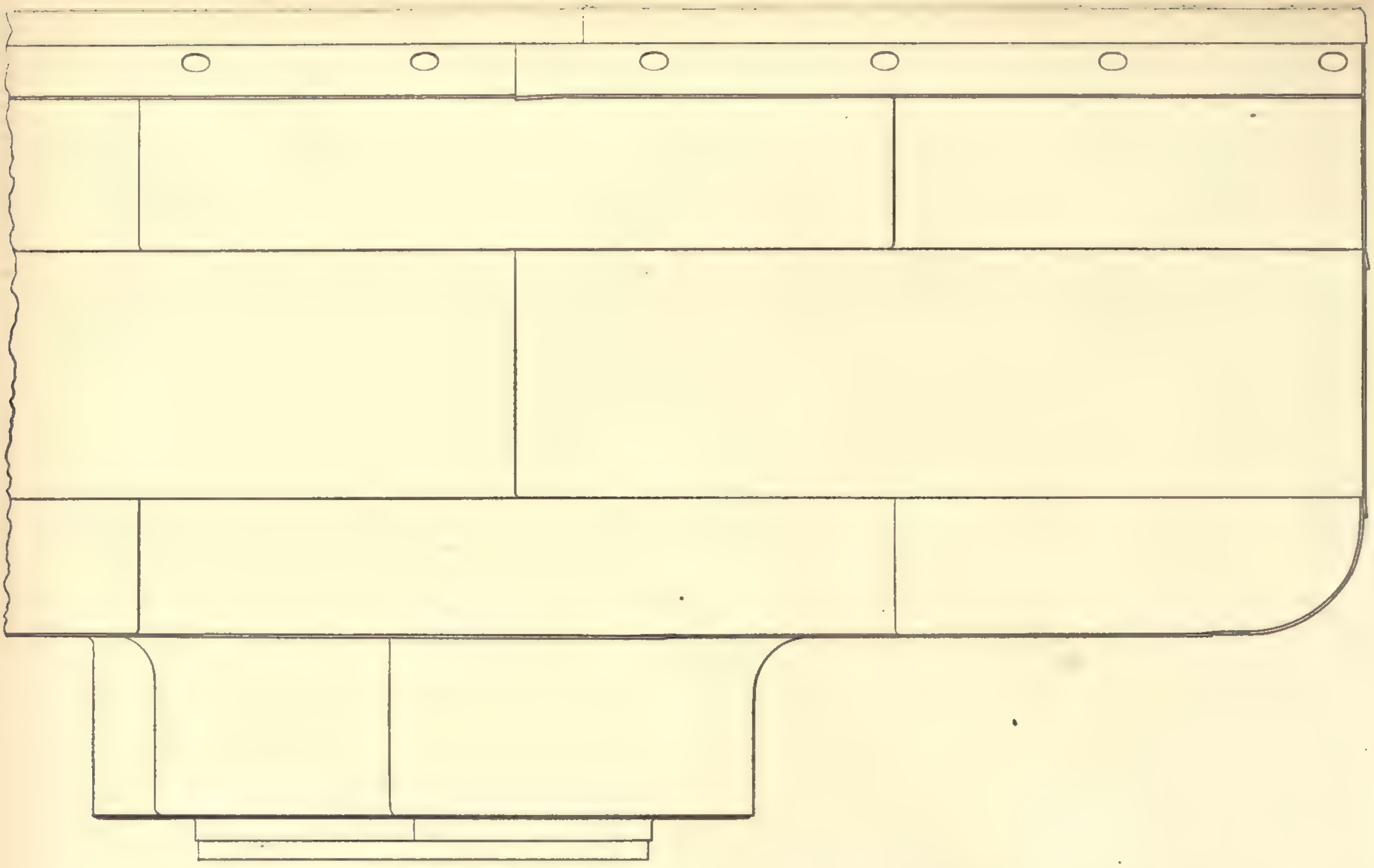


Plate VI.



G.

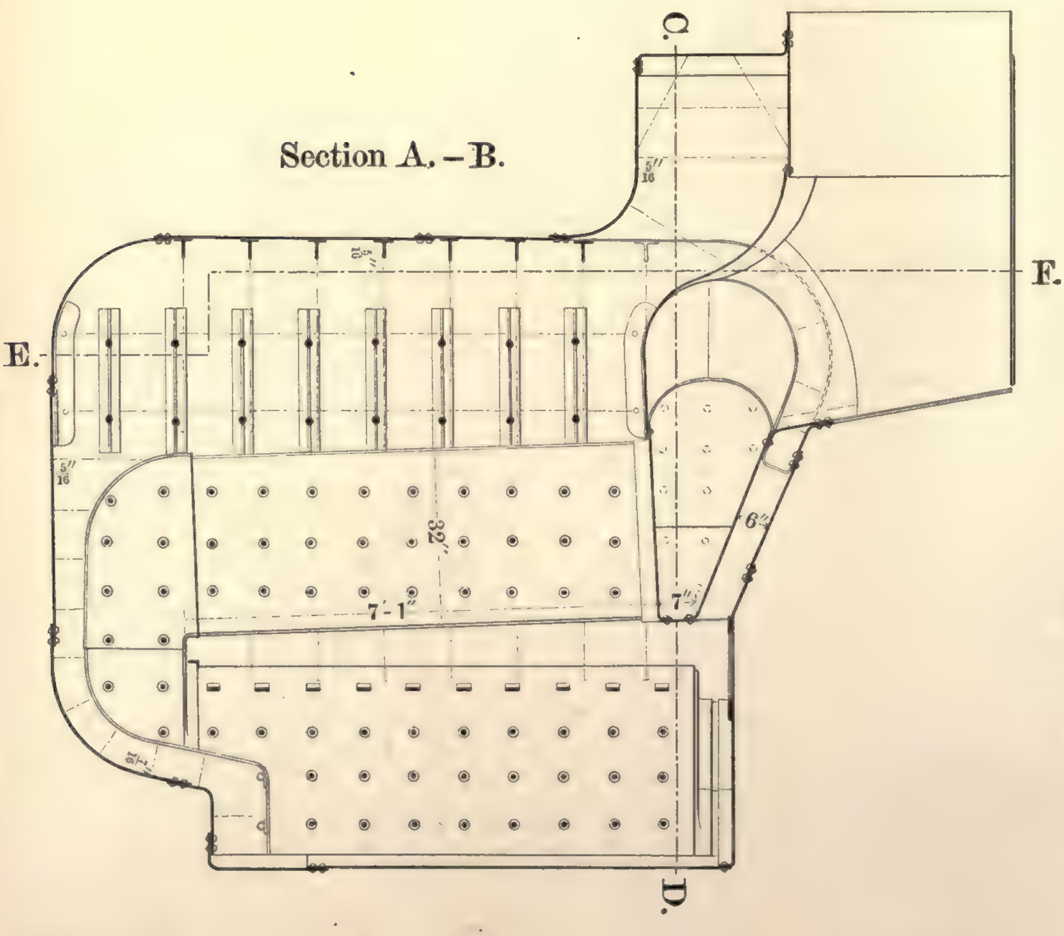


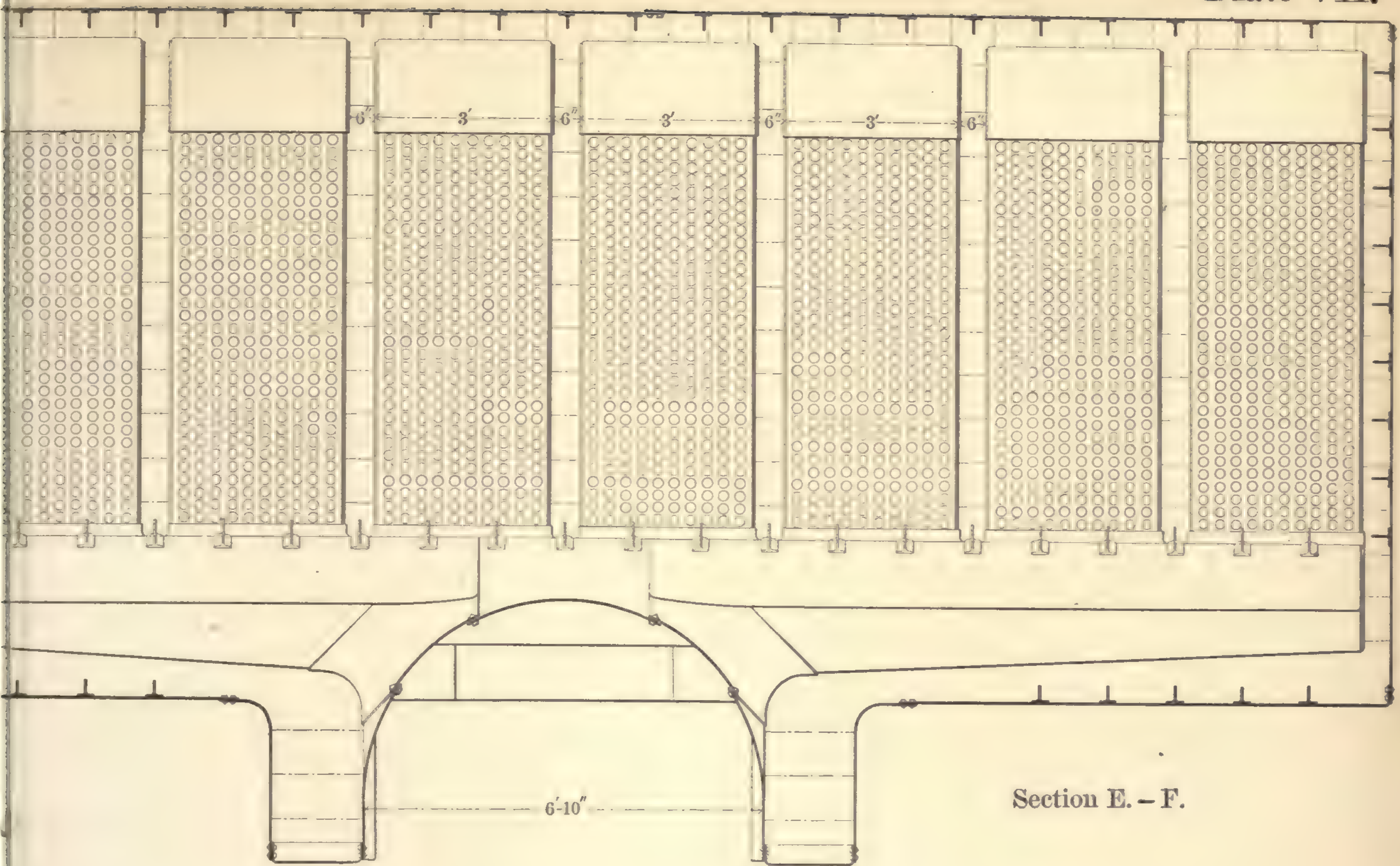


BOILER FOR U. S. S. "LACKAWAN

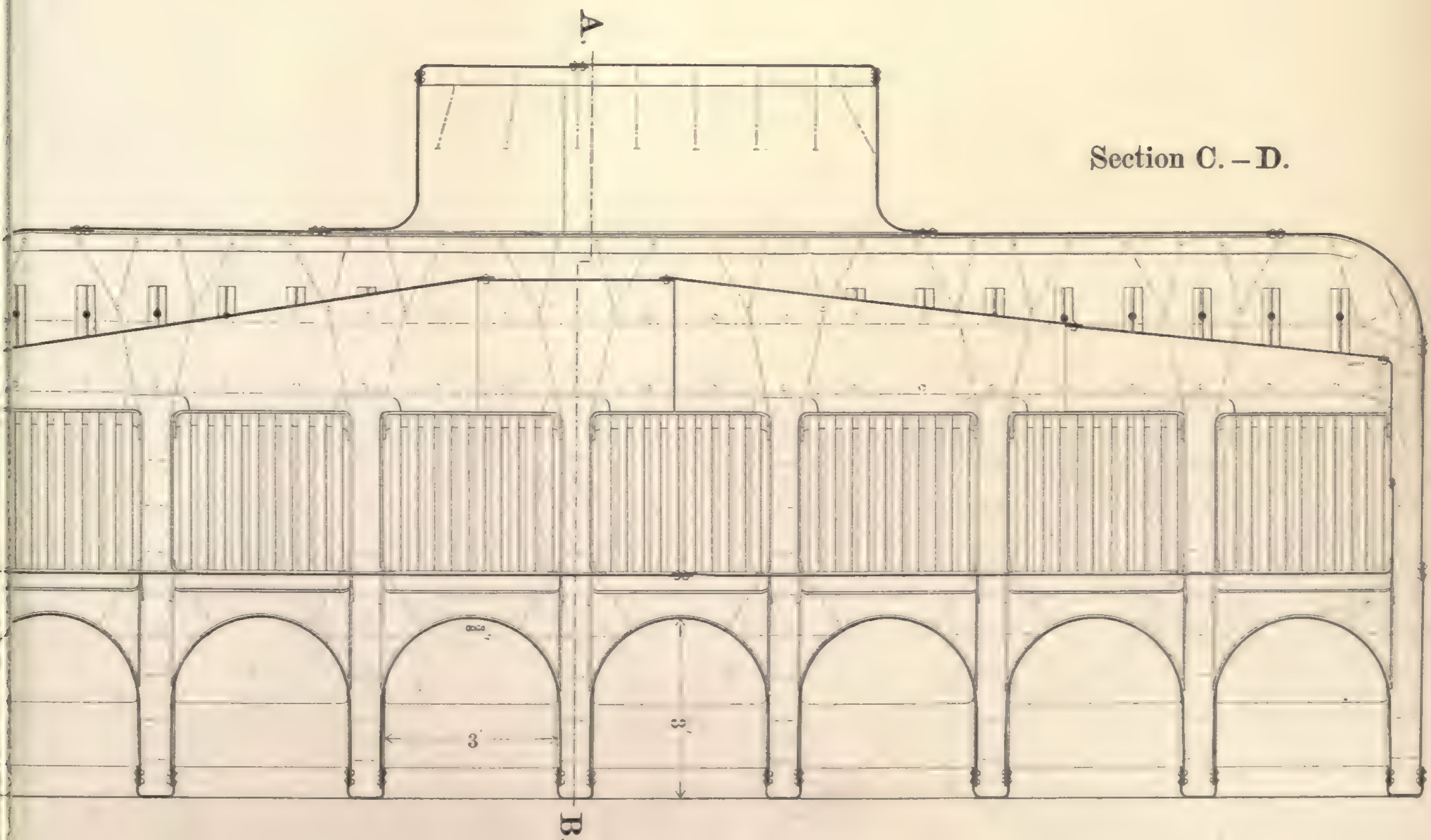
Scale: 12 6 0 1 2 3 4 5 6 7 F

Section A. – B.





Section E. – F.

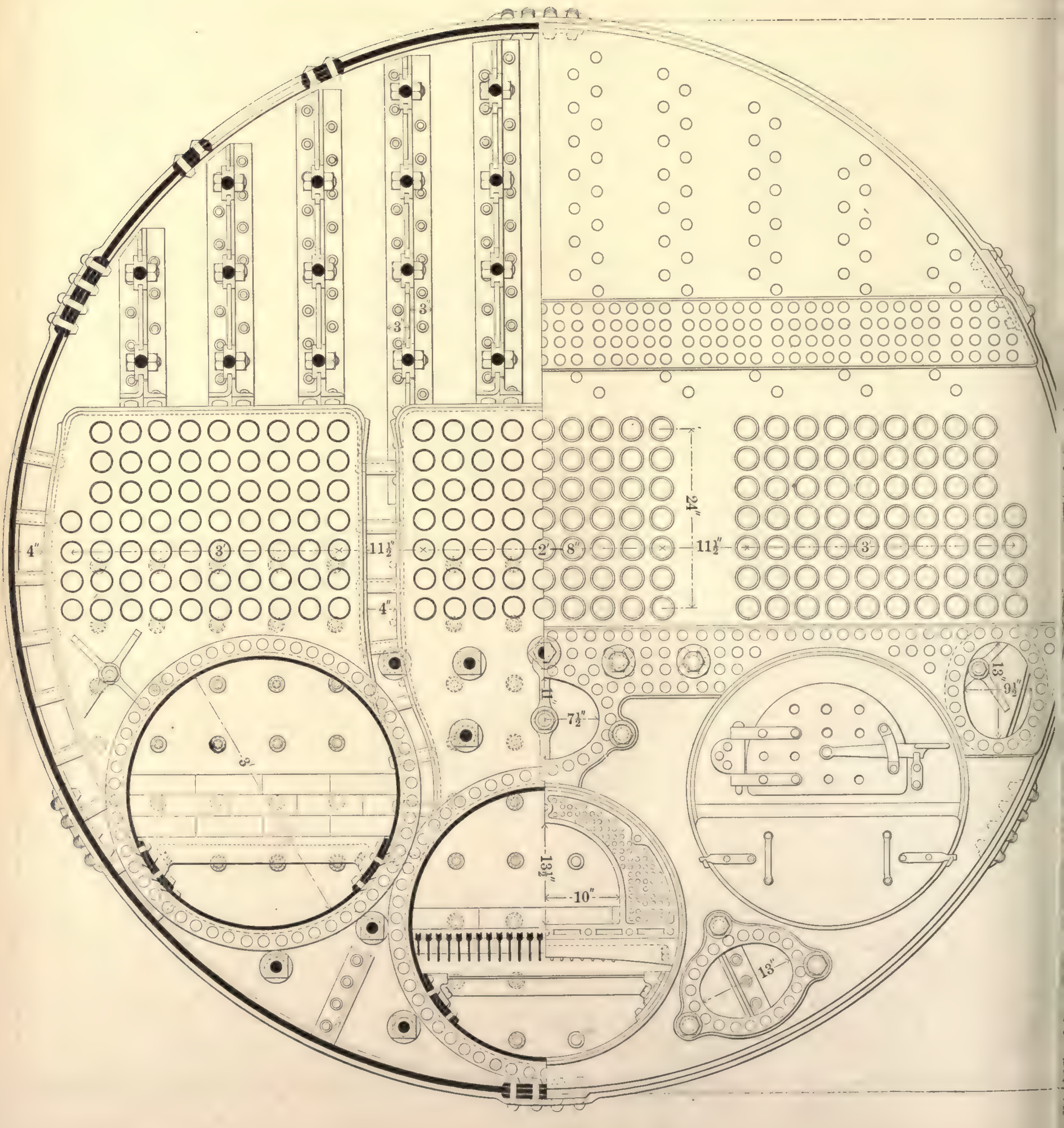


Section C. – D.

SIX BOILERS FOR U. S. S.

BUREAU OF STEAM ENGINEE

Scale: 12 6 0 1

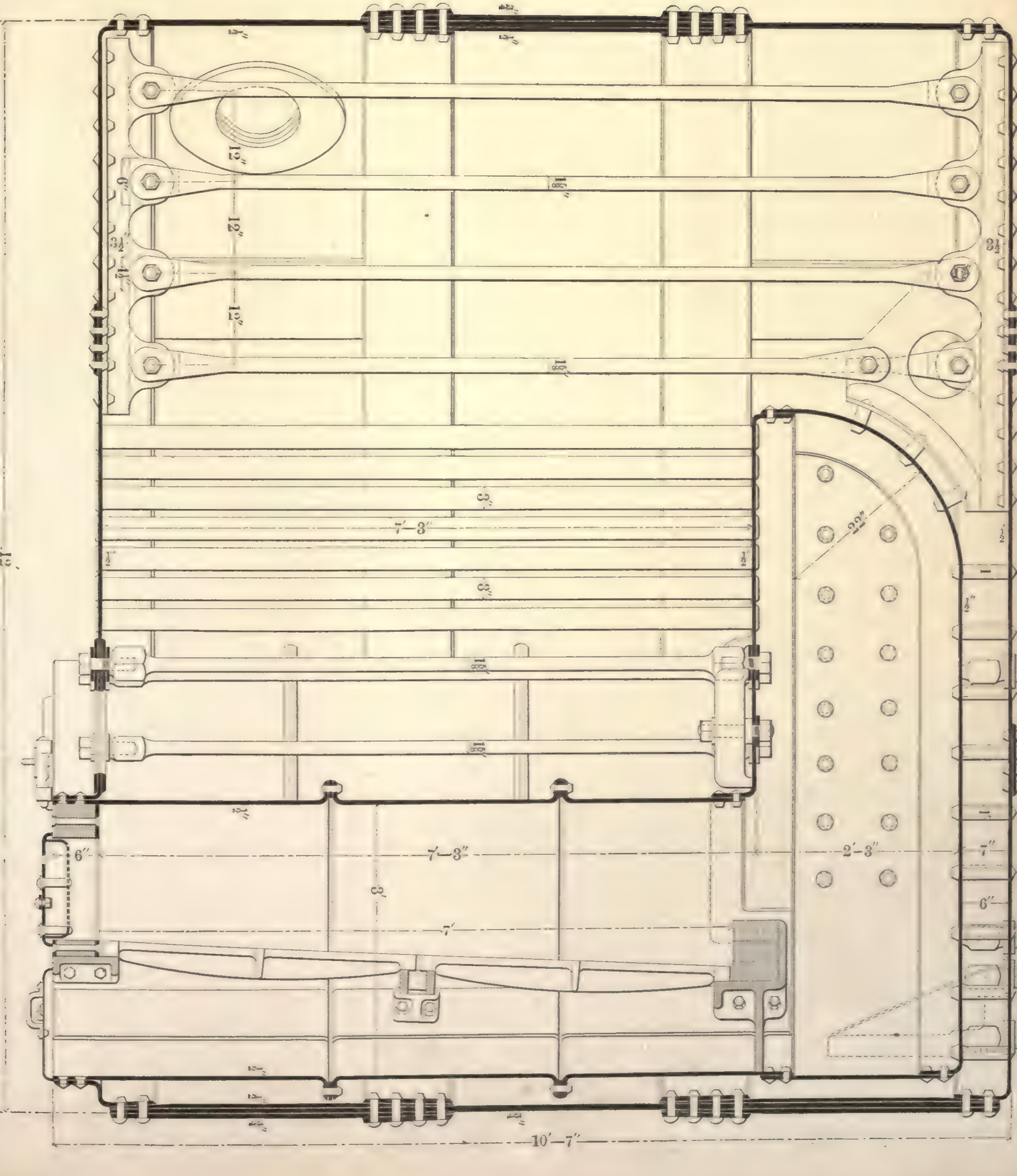


ANTONOMOH & CLASS.

G, U. S. NAVY DEPARTMENT.

3 4 5 Feet.

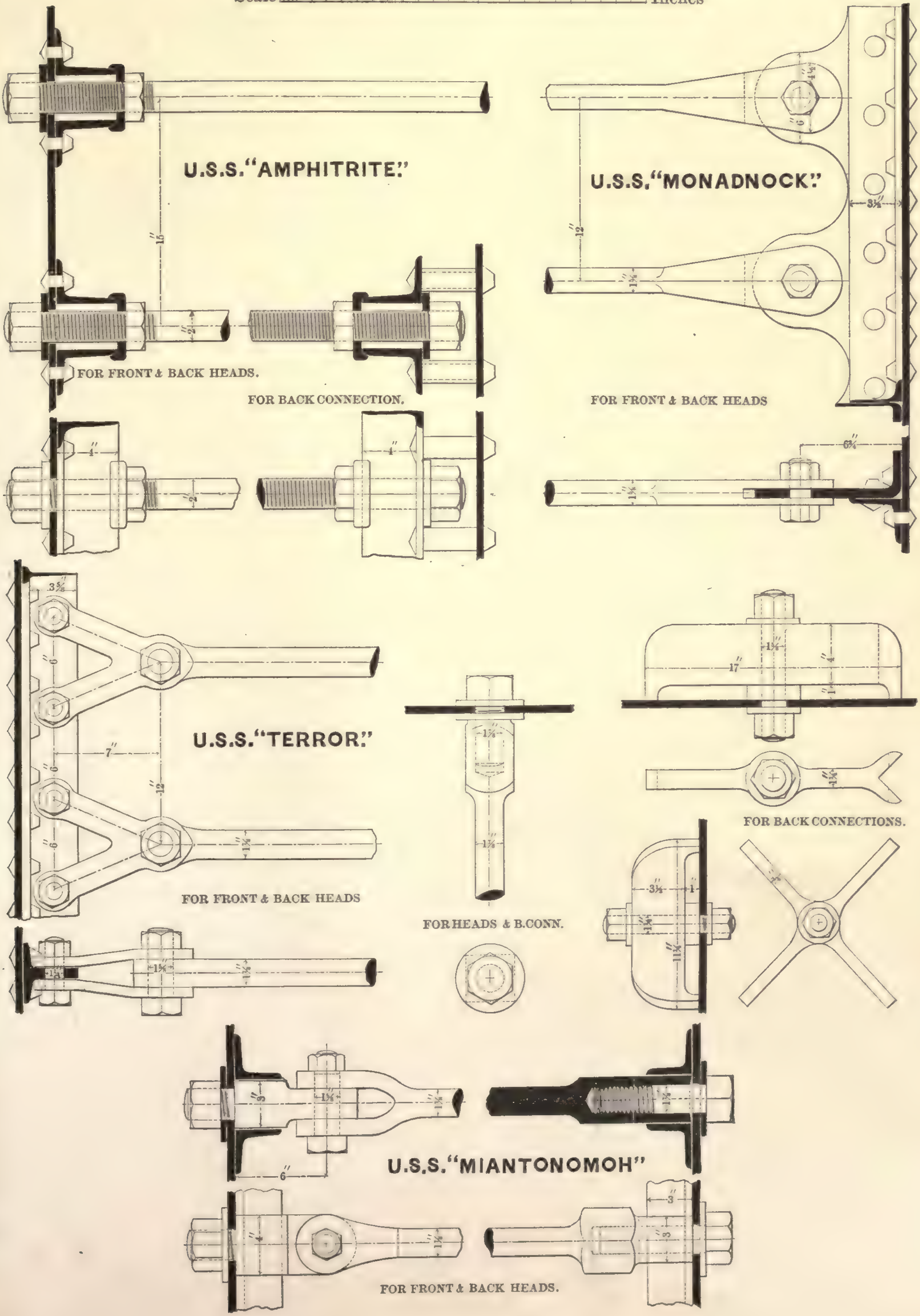
Plate VIII.



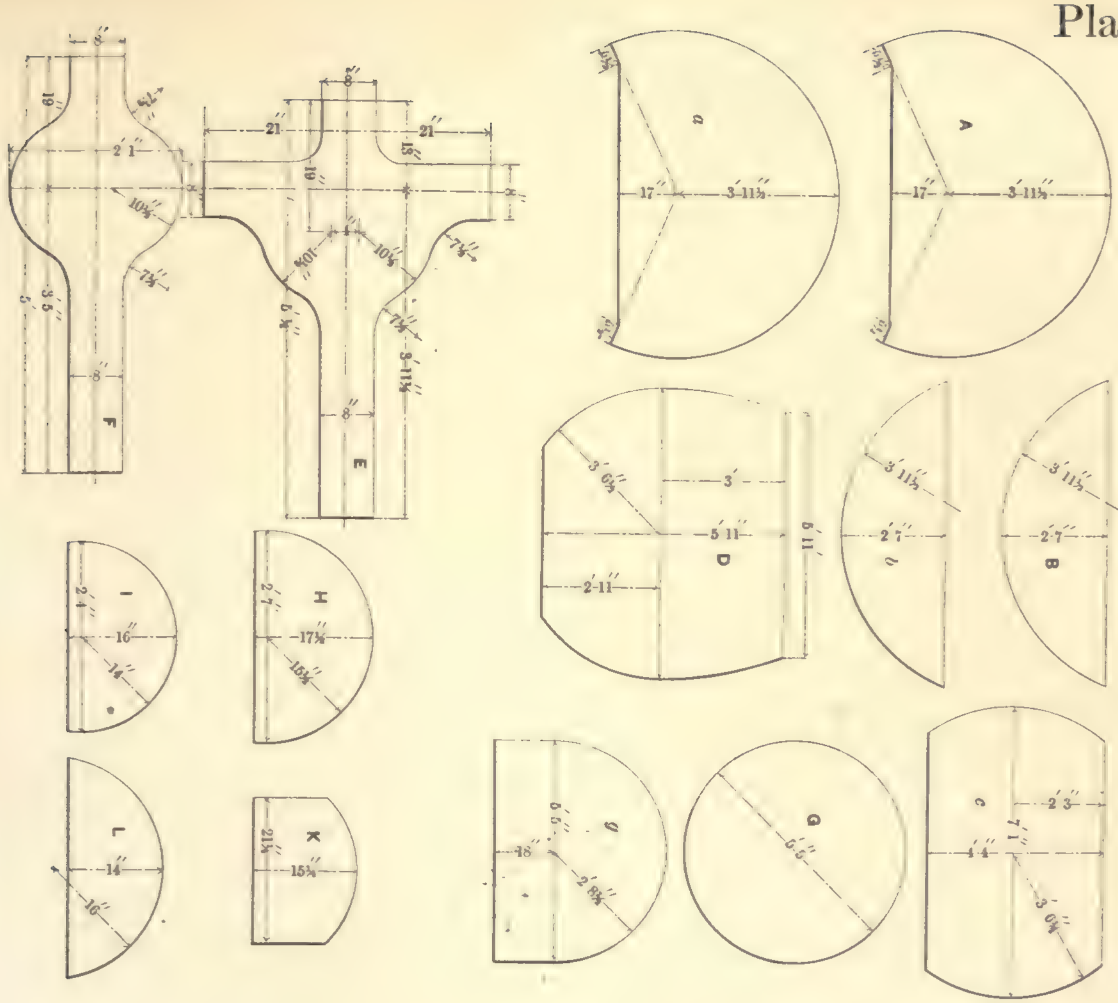
BRACING OF BOILERS

FOR U. S. S. MIANTONOMOH & CLASS.

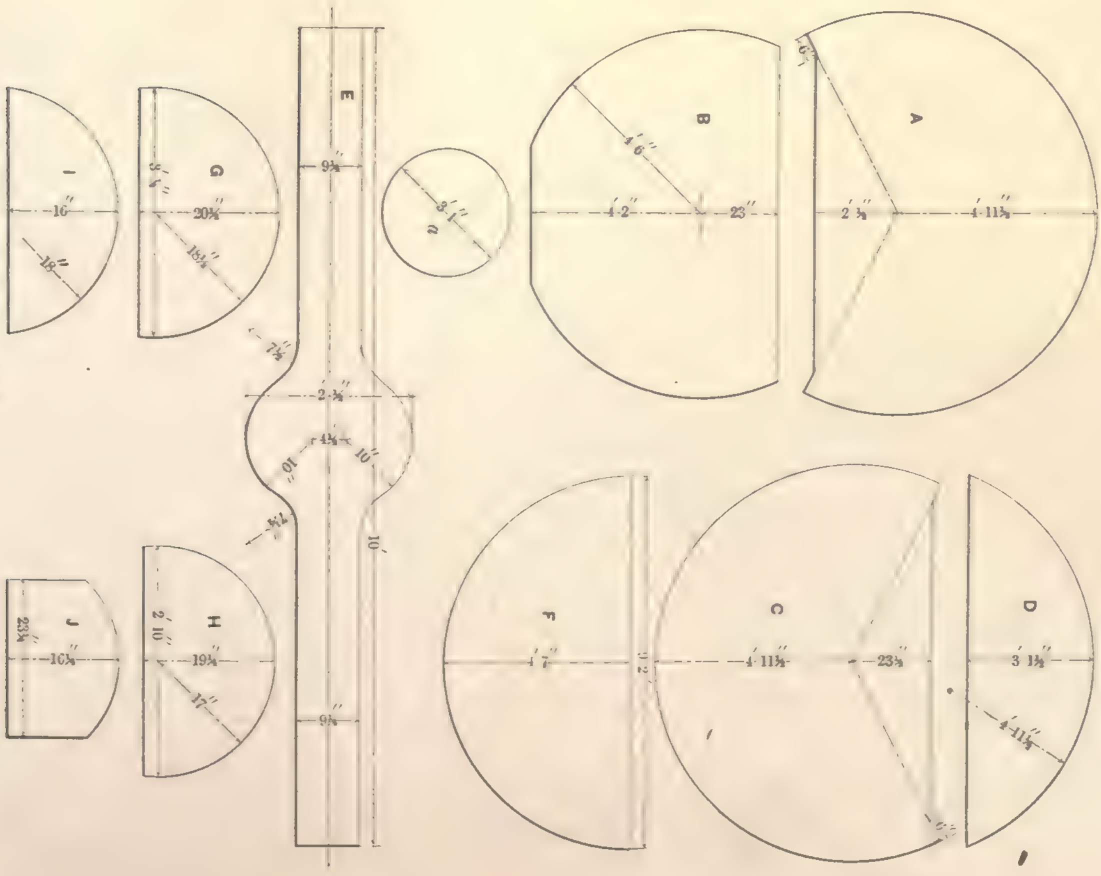
Scale 0 3 6 9 12 15 18 21 24 Inches

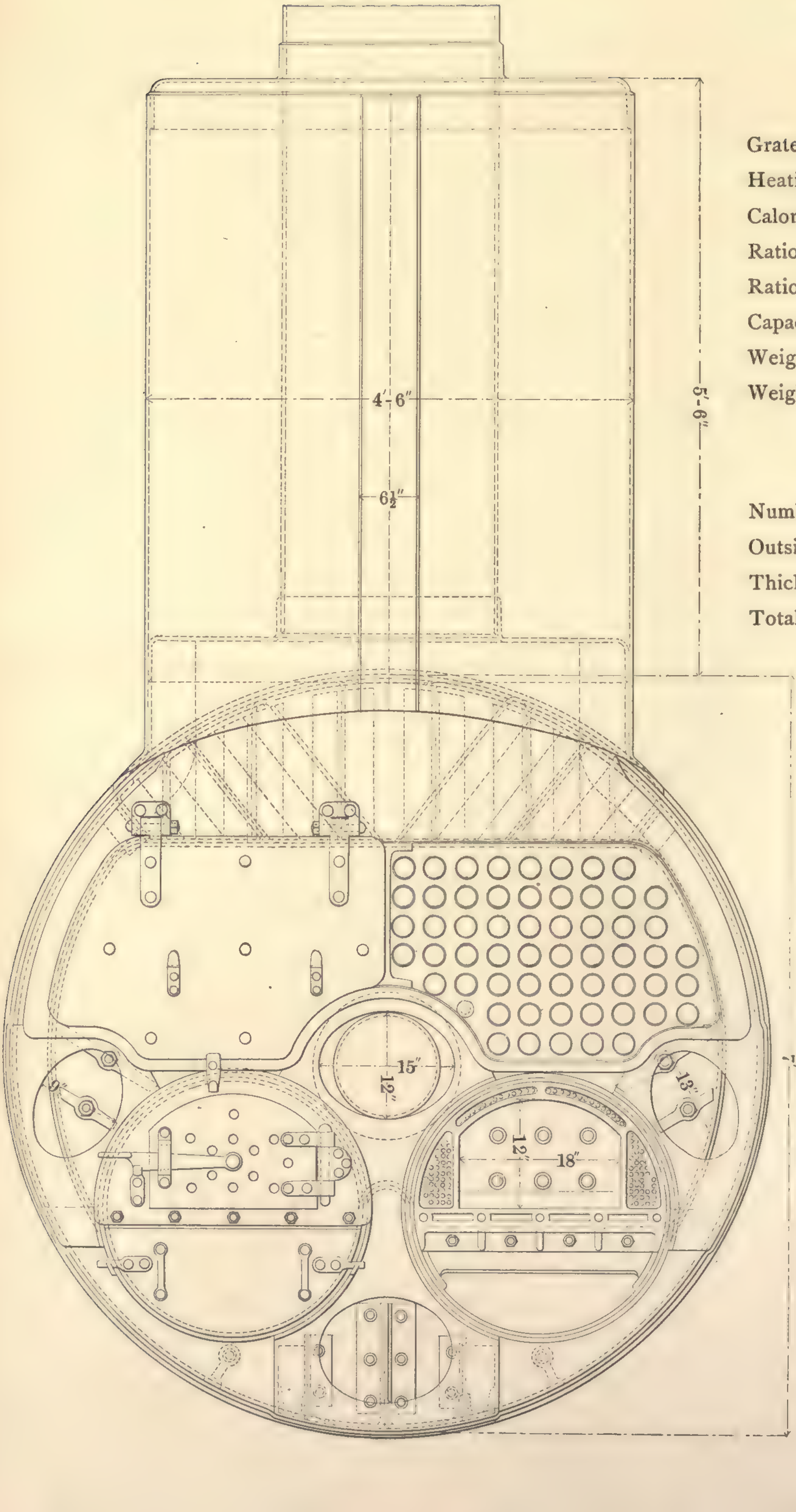


PLATES FOR BOILER OF STEAMER "LOOKOUT."



PLATES FOR BOILERS OF U. S. S. "NIPSIC."





BOILER FOR STEAMER

BUREAU OF STEAM-ENGINEERING,

Grate-surface, ...

Heating-surface, ...

Calorimeter of tubes, ...

Ratio of calorimeter to grate-surface, . . .

Ratio of grate to heating-surface, . . .

Capacity of steam-room, ...

Weight of boiler, ...

Weight of water (to 4½ inches above tubes), .

TUBES.

Number, ...

Outside diameter, ...

Thickness, ...

Total length, ...

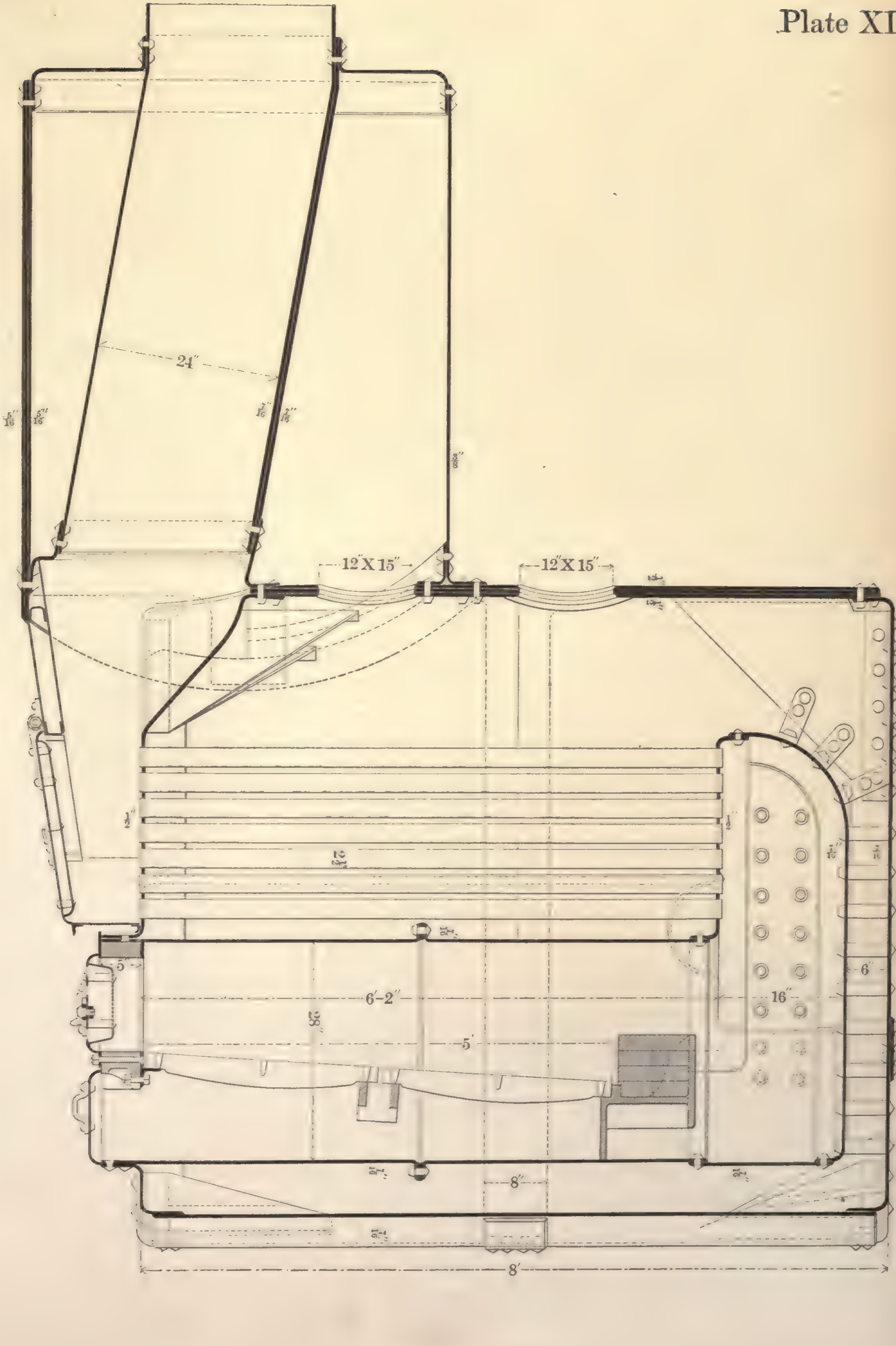
LOOKOUT."

1878.

. . 23.00 sq. ft.
. . 518.97 sq. ft.
. . 3.14 sq. ft.
. . 1 to 7.32
. . 1 to 22.56
. . 94.54 cub. ft.
. . 20,910 lbs.
. . 8,740 lbs.

. . 114
. . $2\frac{1}{2}$ inches.
. . No. 12 W. G.
. . 6 feet $2\frac{3}{8}$ ins.

Plate XI.



SIX BOILERS FOR U. S. S. "NIPSIC."

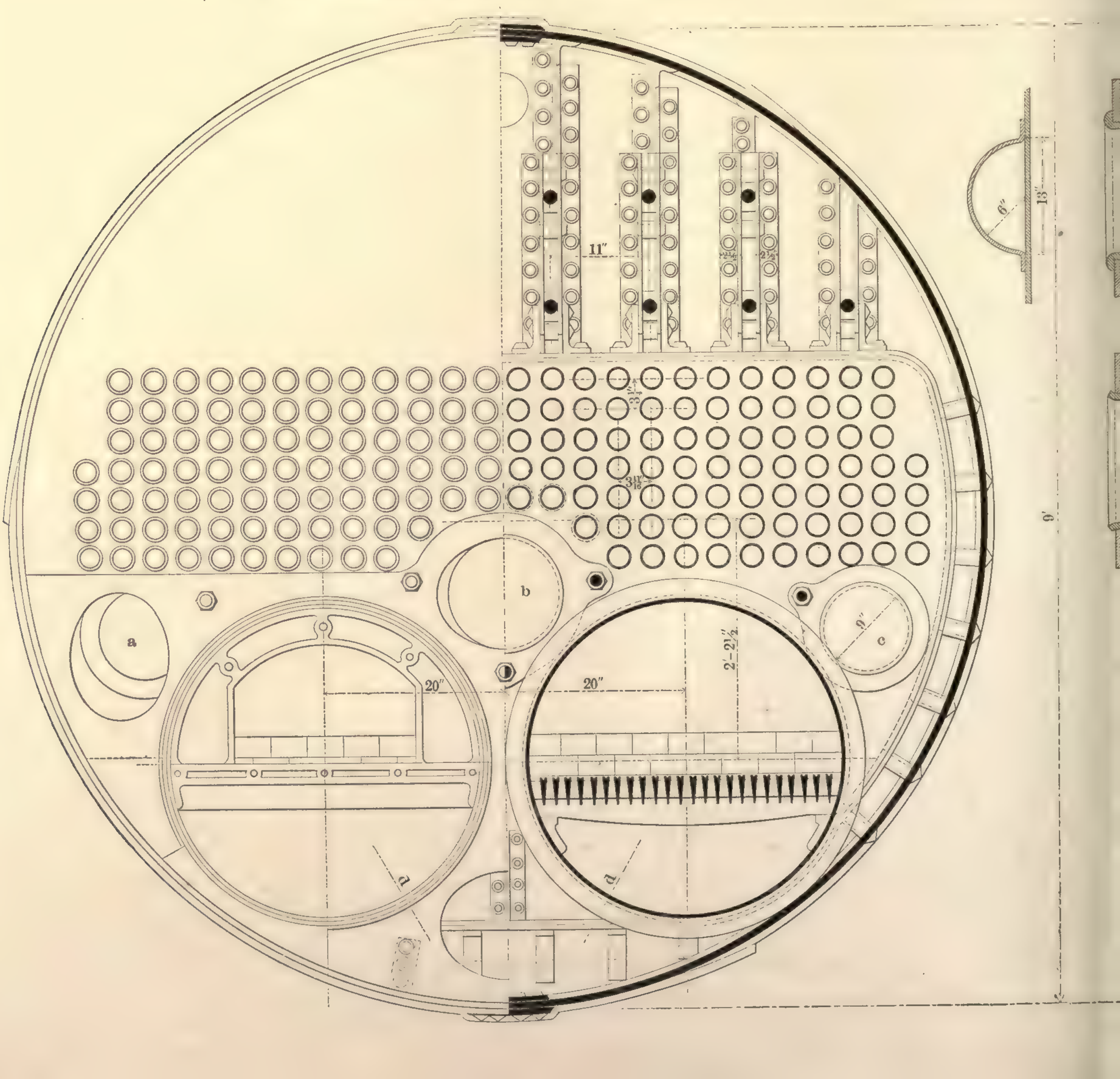
BUREAU OF STEAM-ENGINEERING, JUNE, 1877.

The boilers are to be constructed of the best American charcoal flange-iron. All seams not in contact with th fire to be double-riveted. All the plates to be planed on the edges, the seams to be butt-jointed (planed) and covere with double longitudinal straps on the shell, $\frac{1}{2}$ inch thick; the straps on the heads to be single, $\frac{1}{2}$ inch thick; all t be double-riveted and calked perfectly tight. Gussets and stay-plates to be made of the best flange-iron, eac riveted to the shell and heads by a flange $2\frac{1}{2}$ inches wide, and an angle-iron $2\frac{1}{2} \times 2\frac{1}{2}$ inches; the grain of the iron to b placed in the direction of the strain on the stay-rods. Stay-domes *a*, *b*, *c* to be made of the best flange-iron, $\frac{1}{2}$ inc thick. All plates used in the construction of these boilers to stand a test not less than 55,000 pounds per square inch

The sections of the furnaces are to be riveted together so as to bring all the welded seams in line with eac other. Special care must be taken to have the welded seams of the furnaces come below the grate-bars, about on th lines marked *d d*.

The inner row of rivets around manhole to be countersunk, flush on the inside. Tubes to be of drawn bras and to be expanded by the Prosser tool.

Scale: 12 6 0 1 2 Feet.



THICKNESS OF PLATES.

Shell and circular butt-straps,	$\frac{11}{16}$ inch.
Heads and back-connections,	$\frac{1}{2}$ "
Tube-sheets,	$\frac{9}{16}$ "
Furnaces,	$\frac{7}{16}$ "
Gussets and angle-irons,	$\frac{1}{2}$ "

WEIGHTS.

Wrought-iron,	22,213 lbs.
Cast-iron,	2,469 lbs.
Tubes, brass,	2,665 lbs.
Total weight of boiler,	27,347 lbs.
Weight of fresh water, 6 inches above tubes,	13,060 lbs.

RIVETS.

Diam. of rivets for shell $\frac{7}{8}$ inch, pitch $2\frac{3}{8}$ ins.

Do. do. heads $\frac{3}{4}$ inch, pitch $2\frac{1}{2}$ ins.

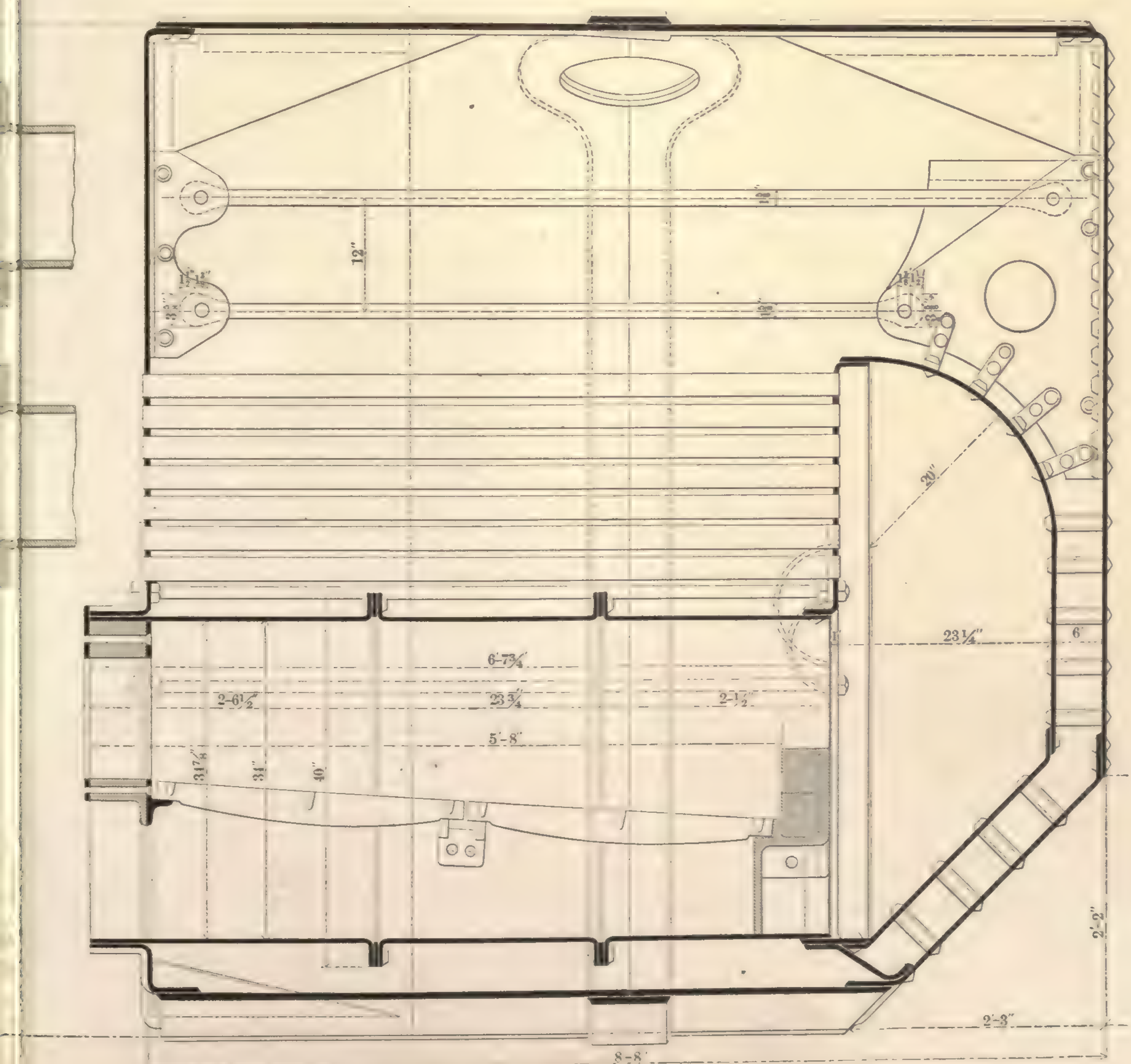
Do. do. connections $\frac{3}{4}$ inch, pitch $1\frac{7}{8}$ ins.

TUBES.

Number,	166.
Outside diameter,	$2\frac{1}{2}$ inches.
Thickness,	No. 13 W. G.
Length,	6 feet 3 inches.

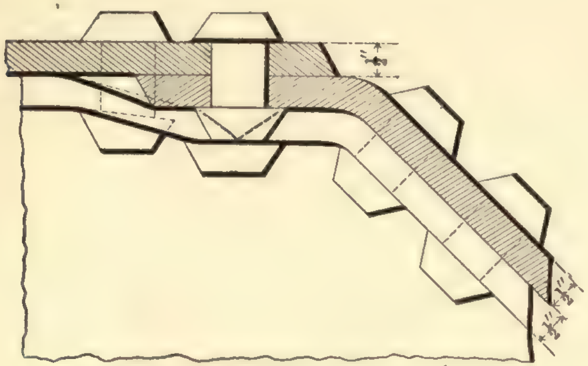
Grate-surface, one boiler,	32.00 sq. ft.
Heating-surface, one boiler,	821.80 sq. ft.
Calorimeter, one boiler,	4.52 sq. ft.

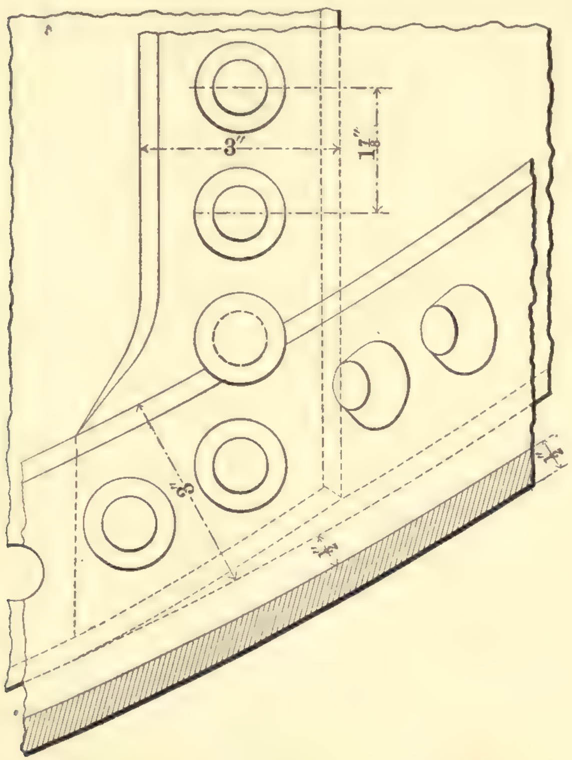
Ratio of grate to heating-surface,	1 to 25.6
" calorimeter to grate-surface,	1 to 7.1

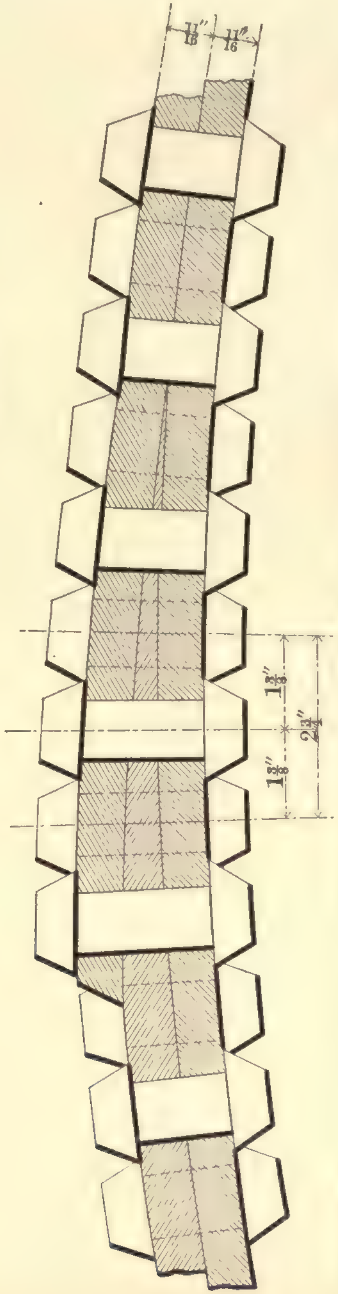


FRONT HEAD AND LONGITUDINAL BUTT STRAPS OF SHELL.

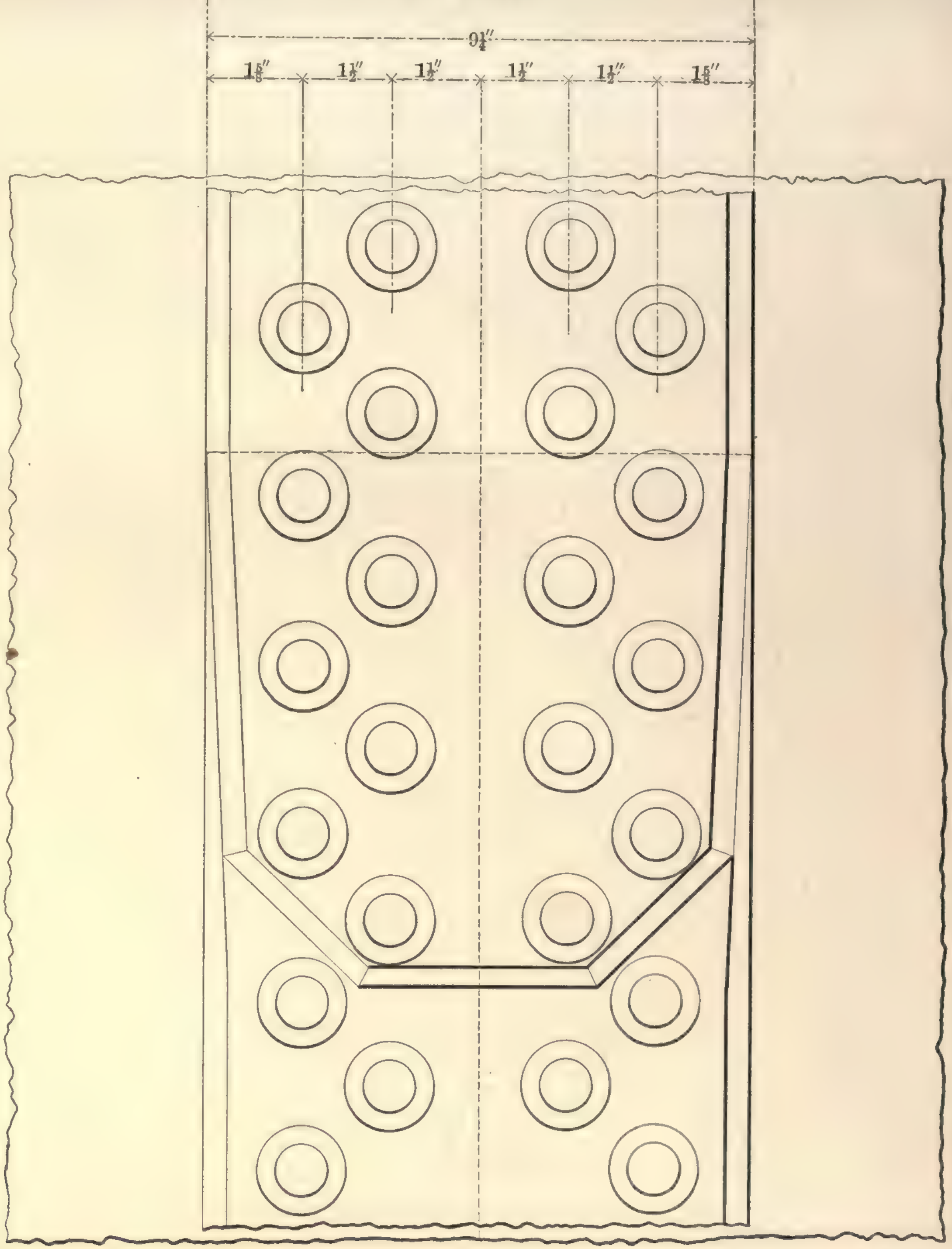
BACK CONNECTION.





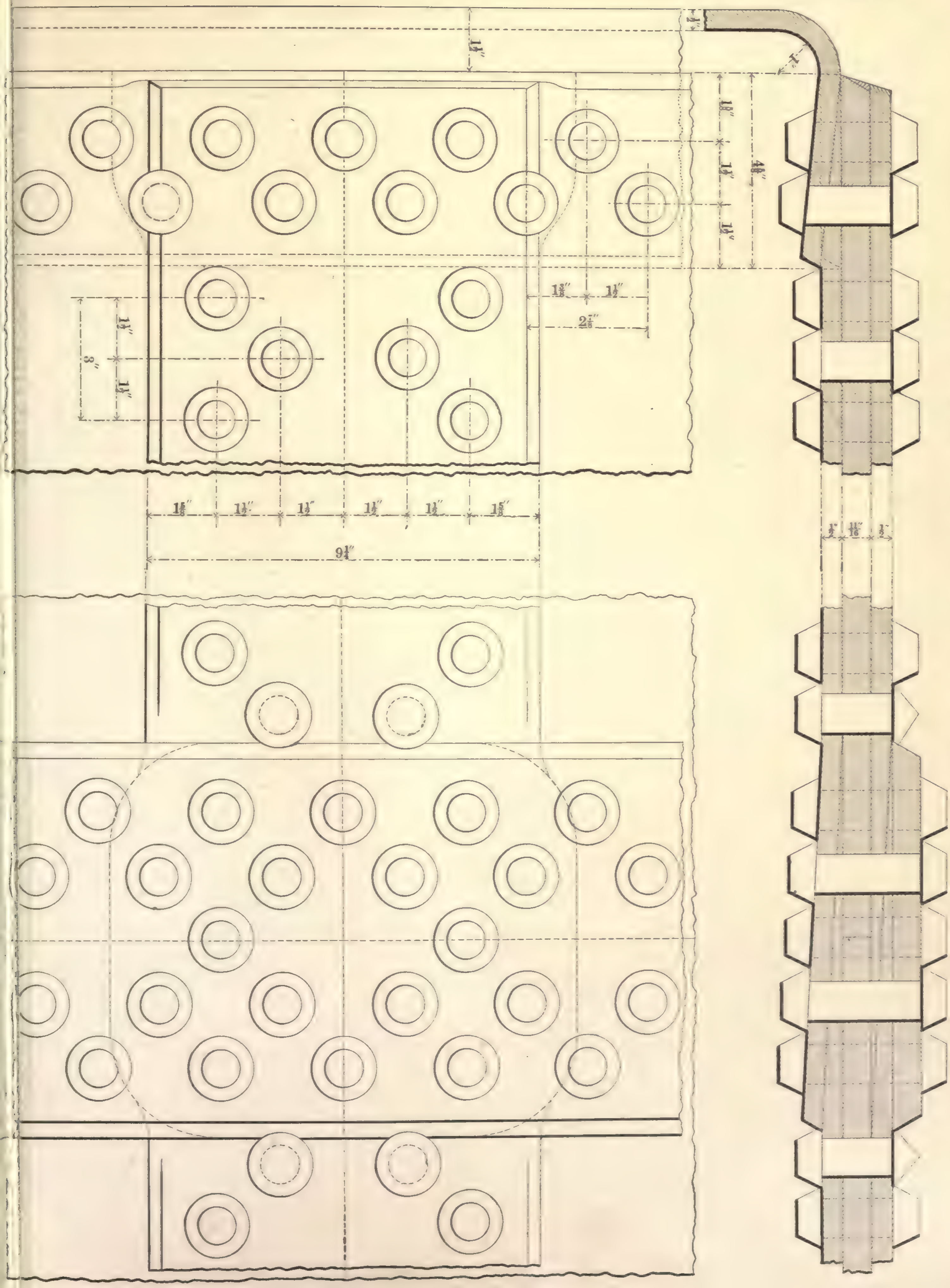


CIRCUMFERENTIAL BUTT STRAP OF SHELL.



J. A. H.

Plate XIII.



DETAILS OF RIVETING OF BOILERS FOR U. S. S. "NIPSIC".

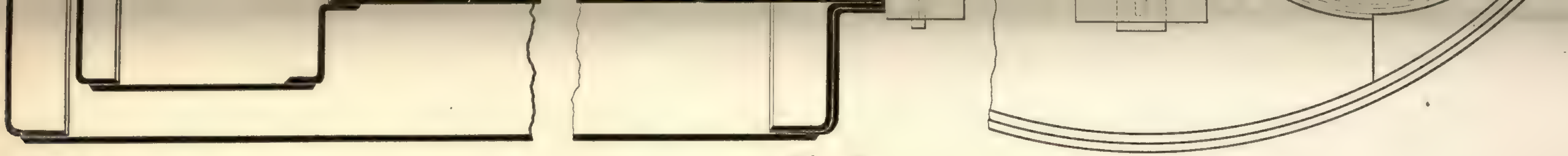


Fig.2.

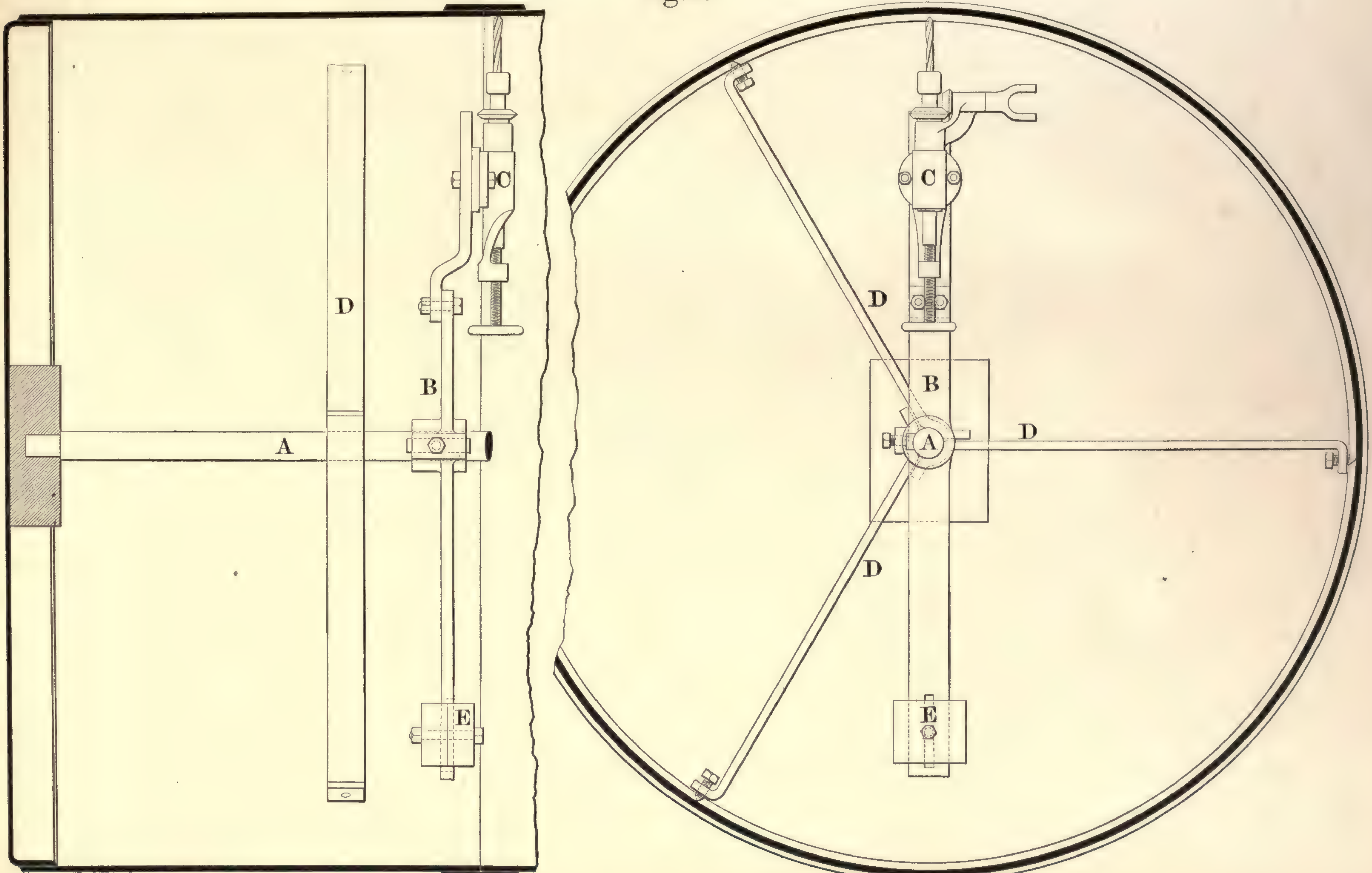


Plate XIV.

METHOD OF DRILLING CYLINDRICAL BOILERS.

NAVY YARD, NORFOLK, VA.,

JUNE, 1879.

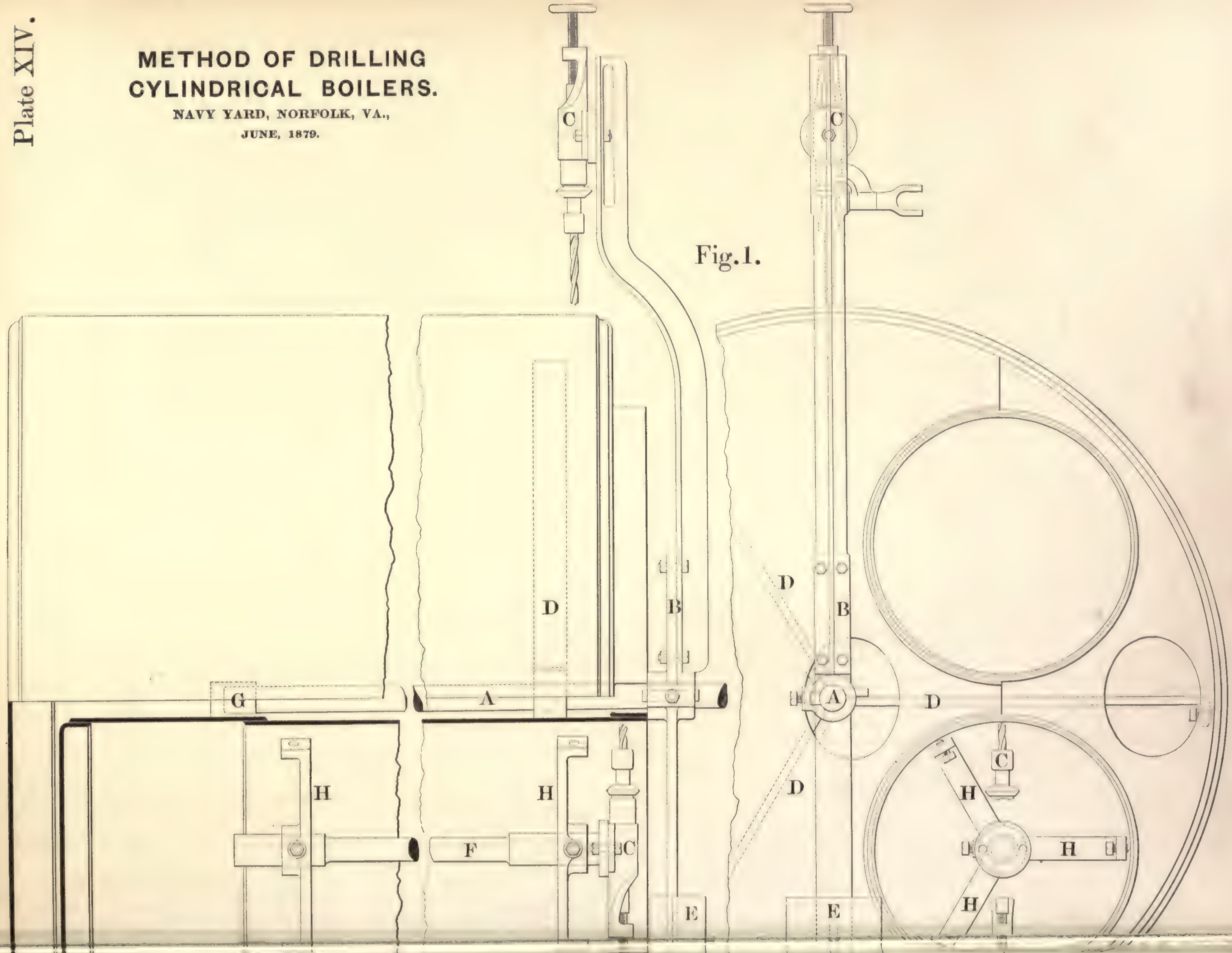


Fig. 1.

TWO BOILERS FOR S. S. "LORD OF THE IS

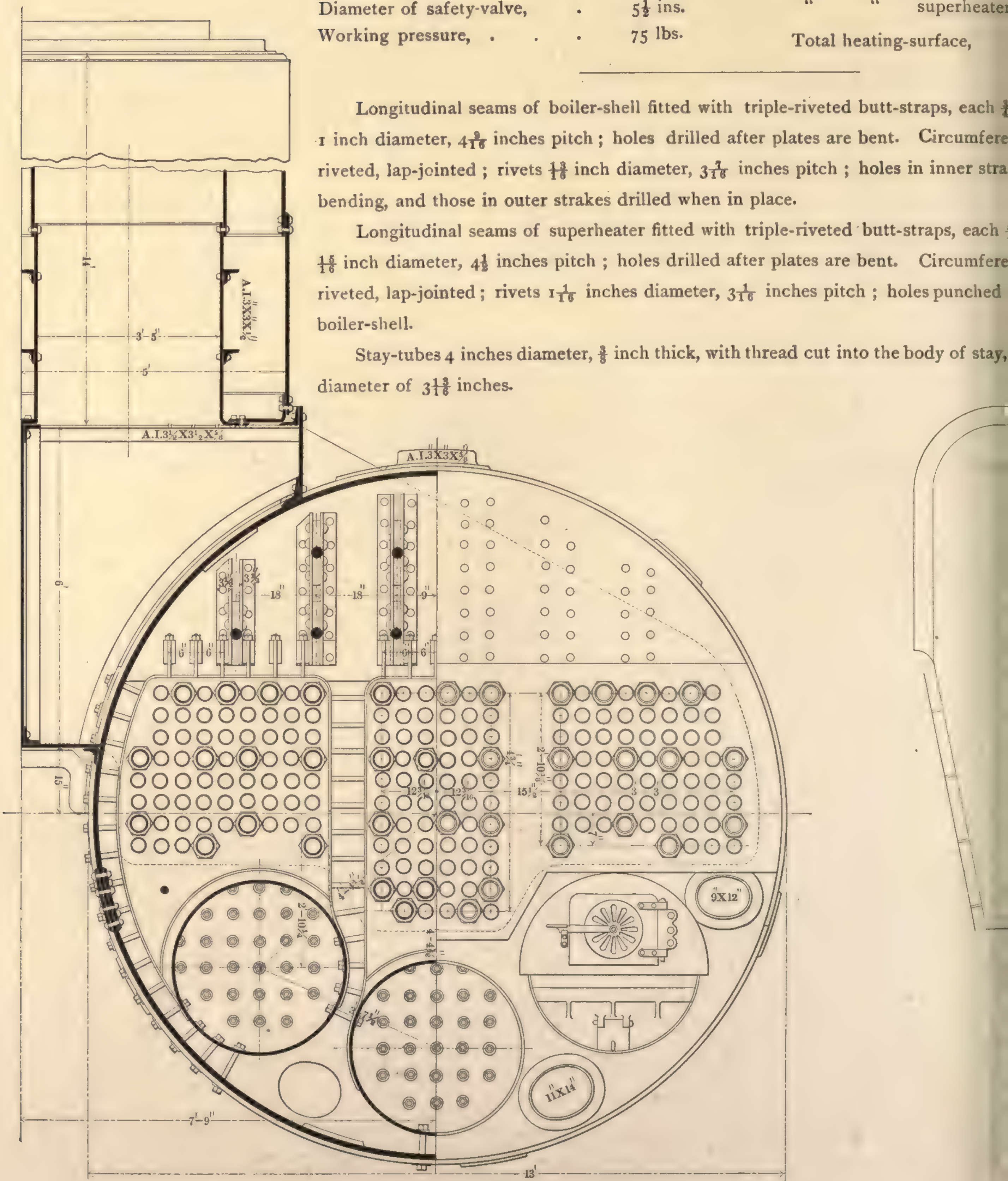
DESIGNED BY ADAM MILLER, LONDON, 1879.

Area of grate-surface, . .	171 sq. ft.	Heating-surface, tubes,	
Number of tubes, . . .	780.	" " plates,	
Diameter of safety-valve, .	$5\frac{1}{2}$ ins.	" " superheater	
Working pressure, . . .	75 lbs.	Total heating-surface,	

Longitudinal seams of boiler-shell fitted with triple-riveted butt-straps, each
1 inch diameter, $4\frac{9}{16}$ inches pitch ; holes drilled after plates are bent. Circumfere
riveted, lap-jointed ; rivets $\frac{15}{16}$ inch diameter, $3\frac{7}{16}$ inches pitch ; holes in inner stra
bending, and those in outer strakes drilled when in place.

Longitudinal seams of superheater fitted with triple-riveted butt-straps, each
$\frac{15}{16}$ inch diameter, $4\frac{1}{2}$ inches pitch ; holes drilled after plates are bent. Circumfere
riveted, lap-jointed ; rivets $1\frac{1}{16}$ inches diameter, $3\frac{1}{16}$ inches pitch ; holes punched
boiler-shell.

Stay-tubes 4 inches diameter, $\frac{3}{8}$ inch thick, with thread cut into the body of stay,
diameter of $3\frac{13}{16}$ inches.



Scale:

s."

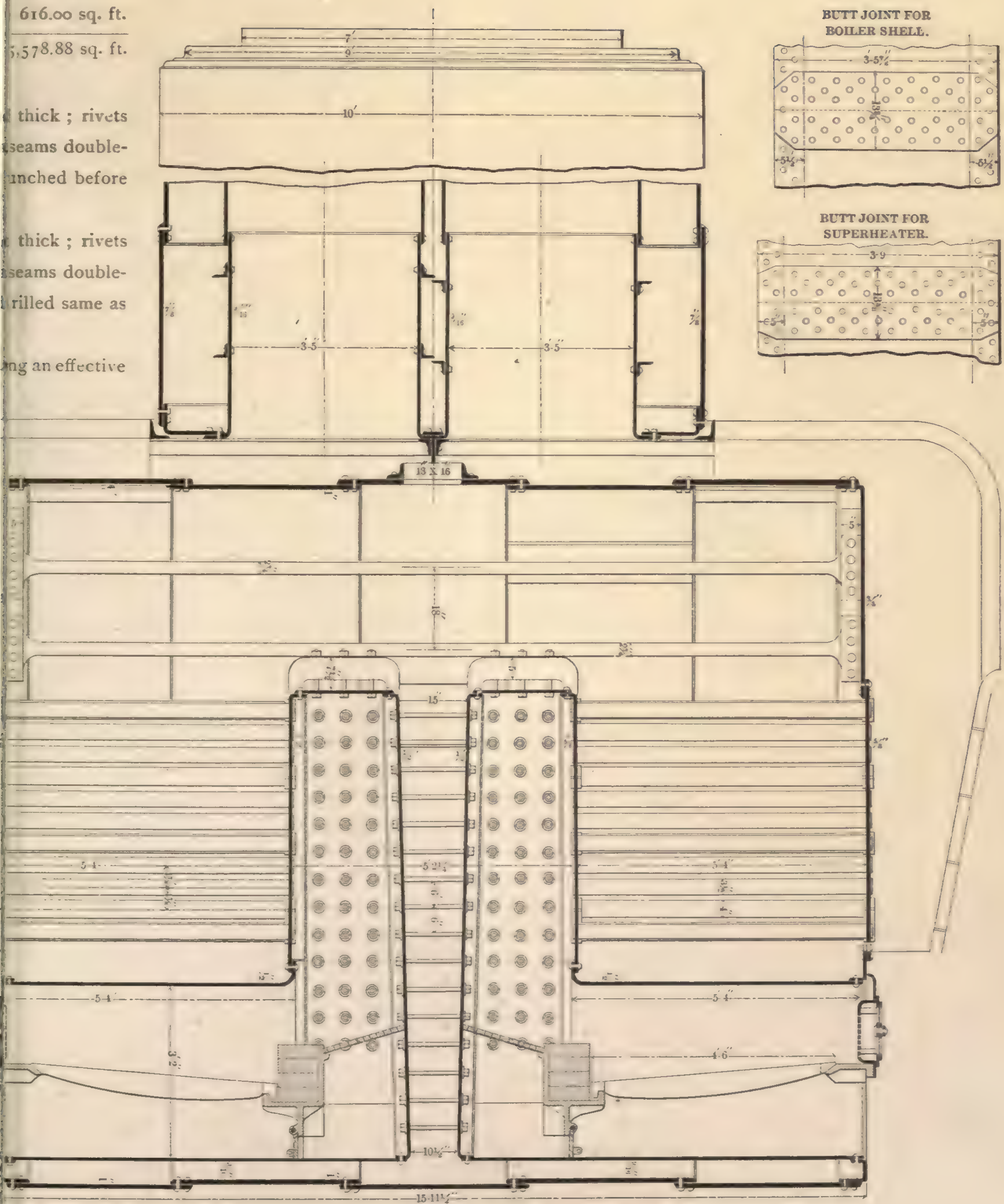
Plate XV.

3,786.88 sq. ft.
1,176.00 sq. ft.
616.00 sq. ft.
5,578.88 sq. ft.

thick ; rivets
seams double-
unched before

thick ; rivets
seams double-
rilled same as

ng an effective

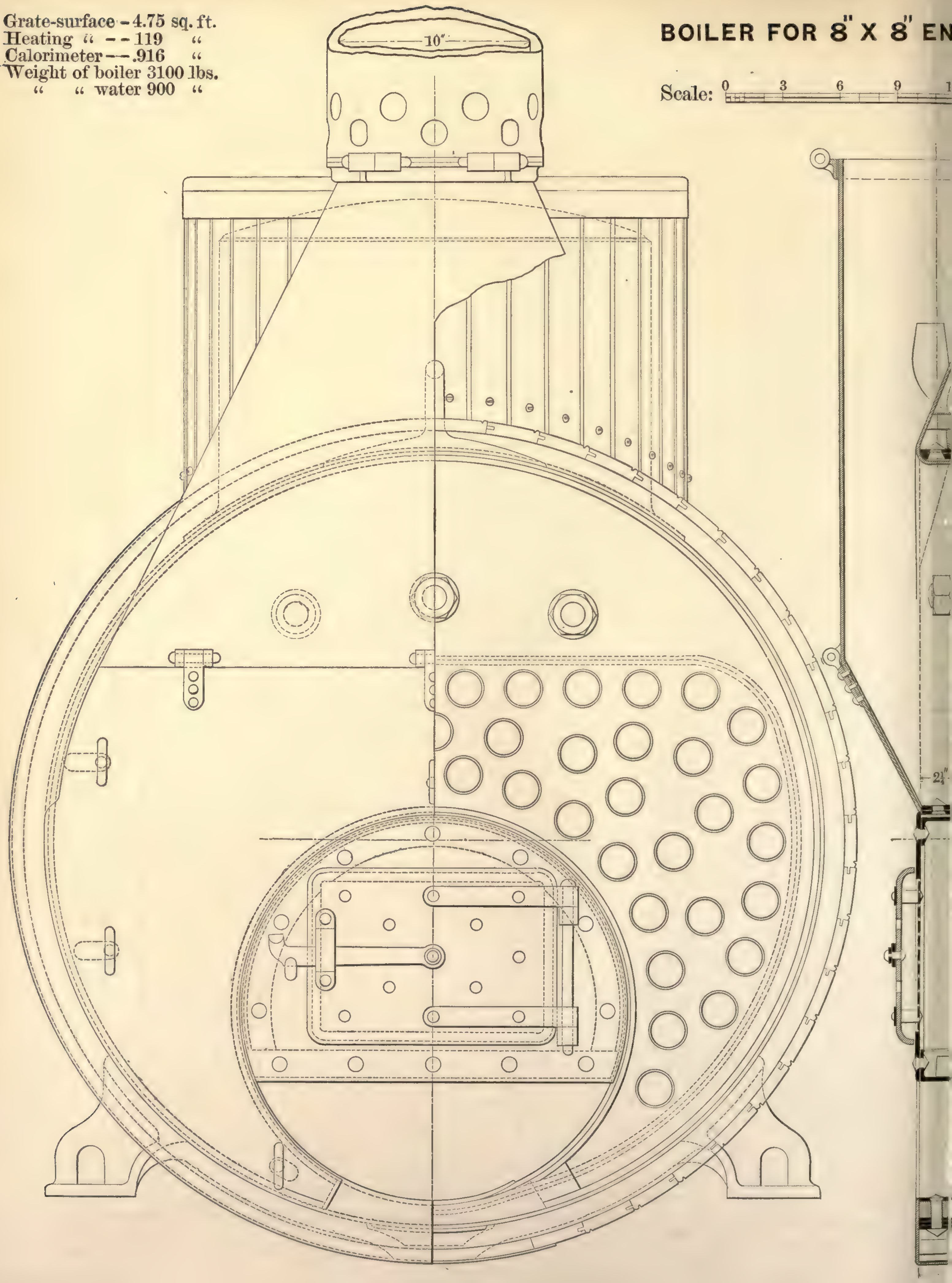


3 4 5 6 Feet.

Grate-surface - 4.75 sq. ft.
Heating " - - 119 "
Calorimeter - - .916 "
Weight of boiler 3100 lbs.
" " water 900 "

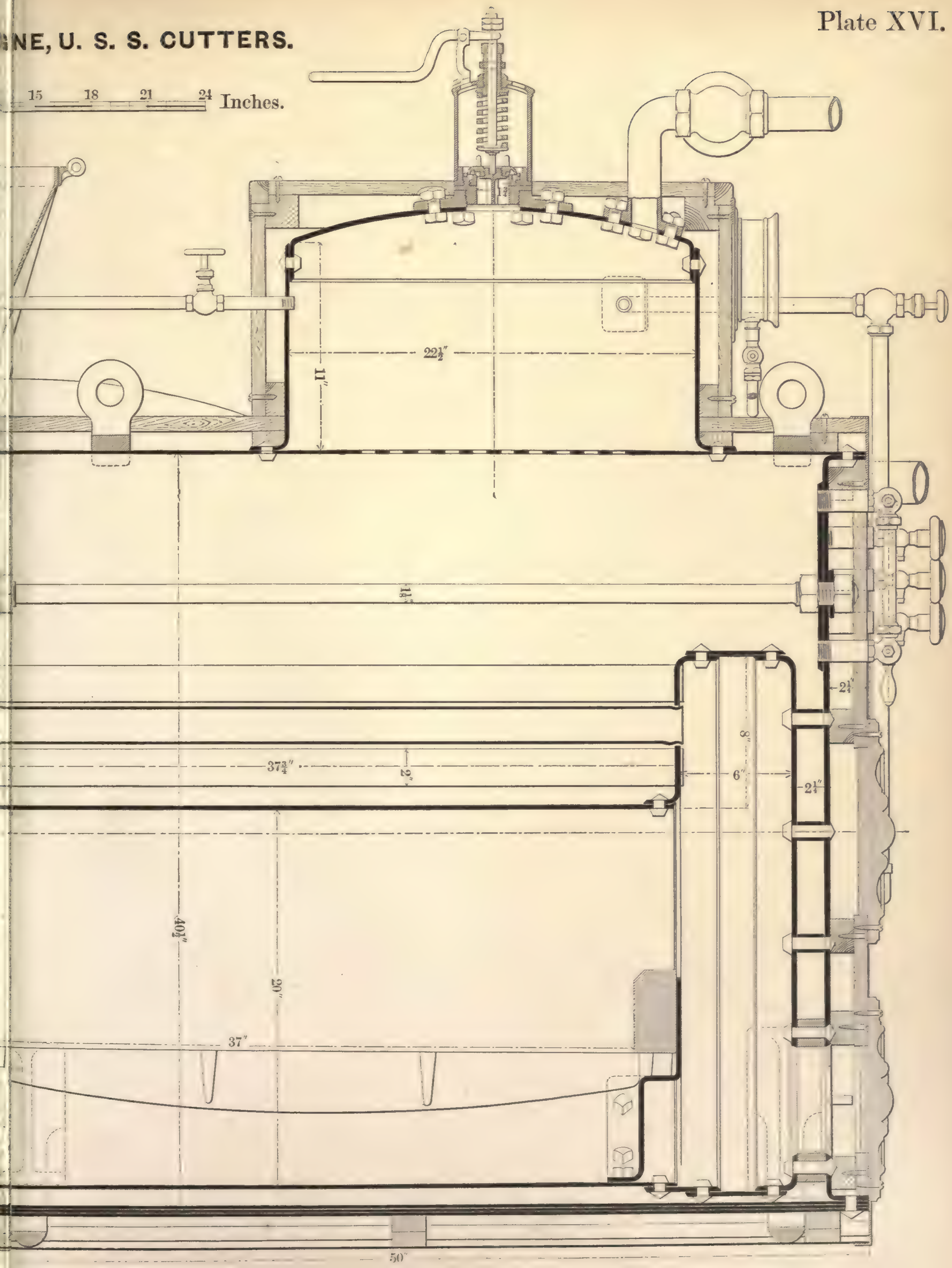
BOILER FOR 8" X 8" EN

Scale: 0 3 6 9 1



GNE, U. S. S. CUTTERS.

Plate XVI.



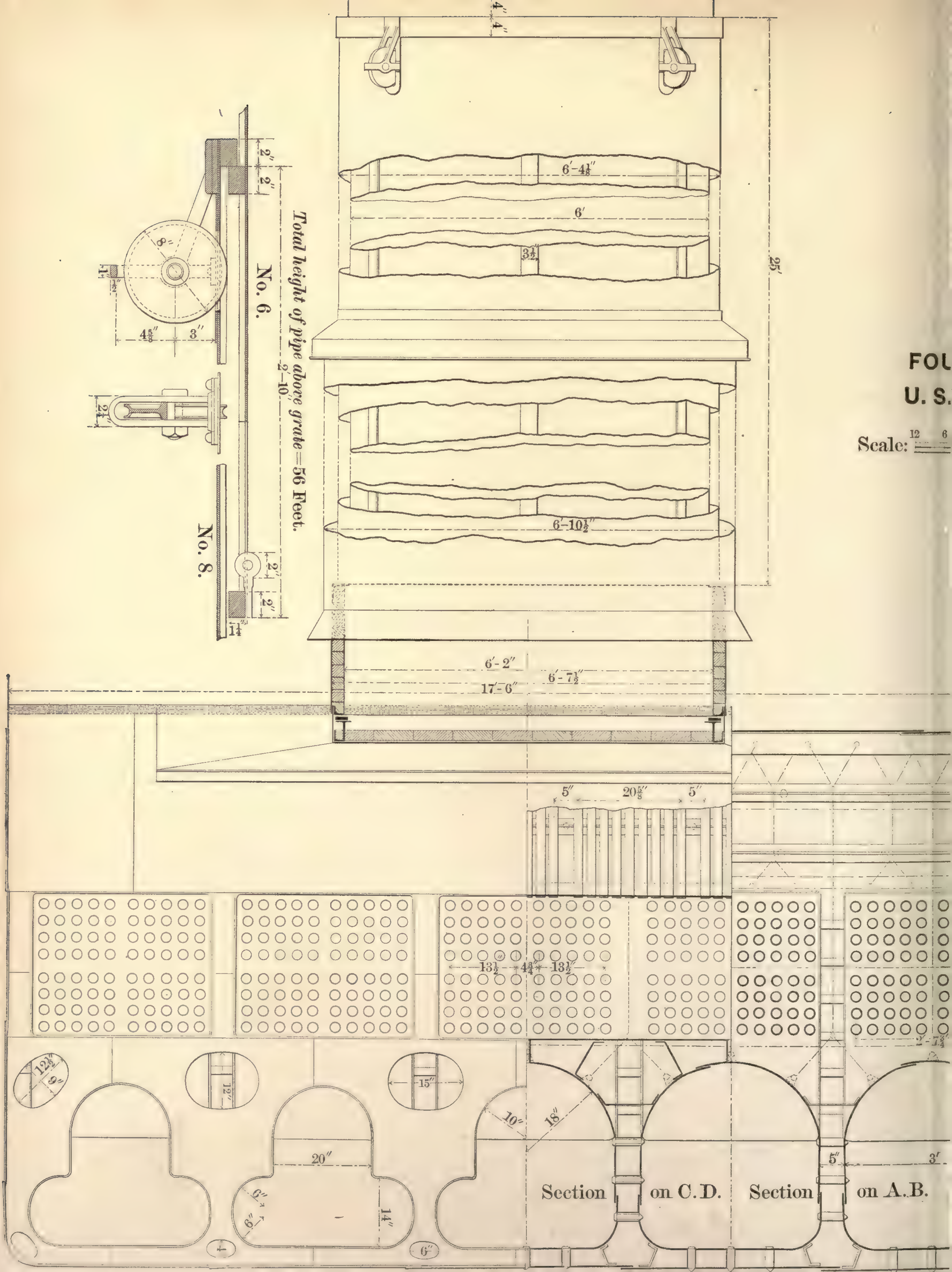

FOU
U. S.
Scale:
Total height of pipe above grate=56 Feet.
No. 6.
No. 8.
6′-4⅛″
6′
3½
25′
6′-10½″
6′-2″
6′-7½″
17′-6″
5″
20⅝″
5″
13½
4¾″
13½
Section
on C. D.
Section
on A. B.
20″
14″
10″
18″
15″
12″
2′-7¾″
3′
5″

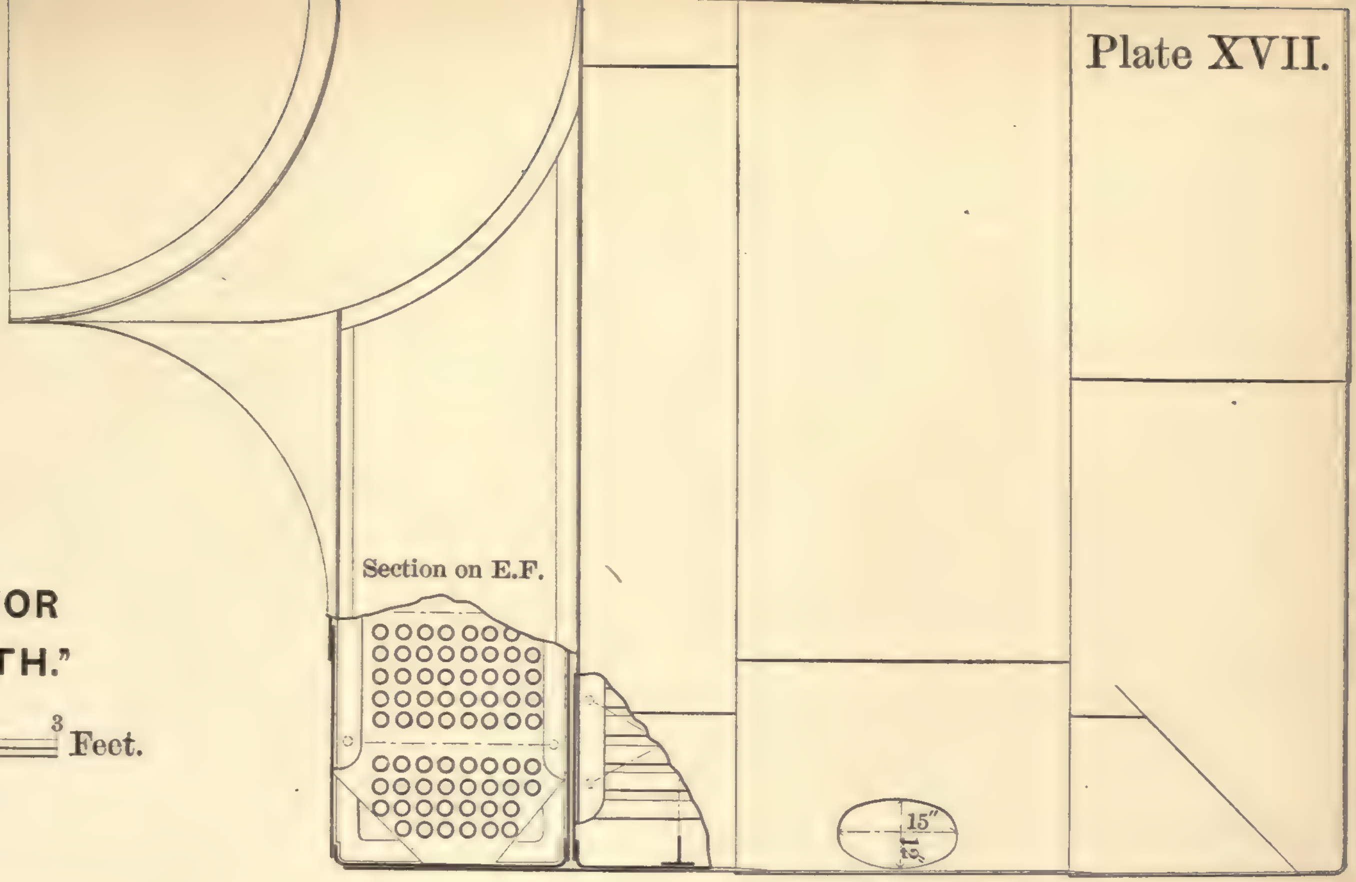
Plate XVII.

Plate XVII.

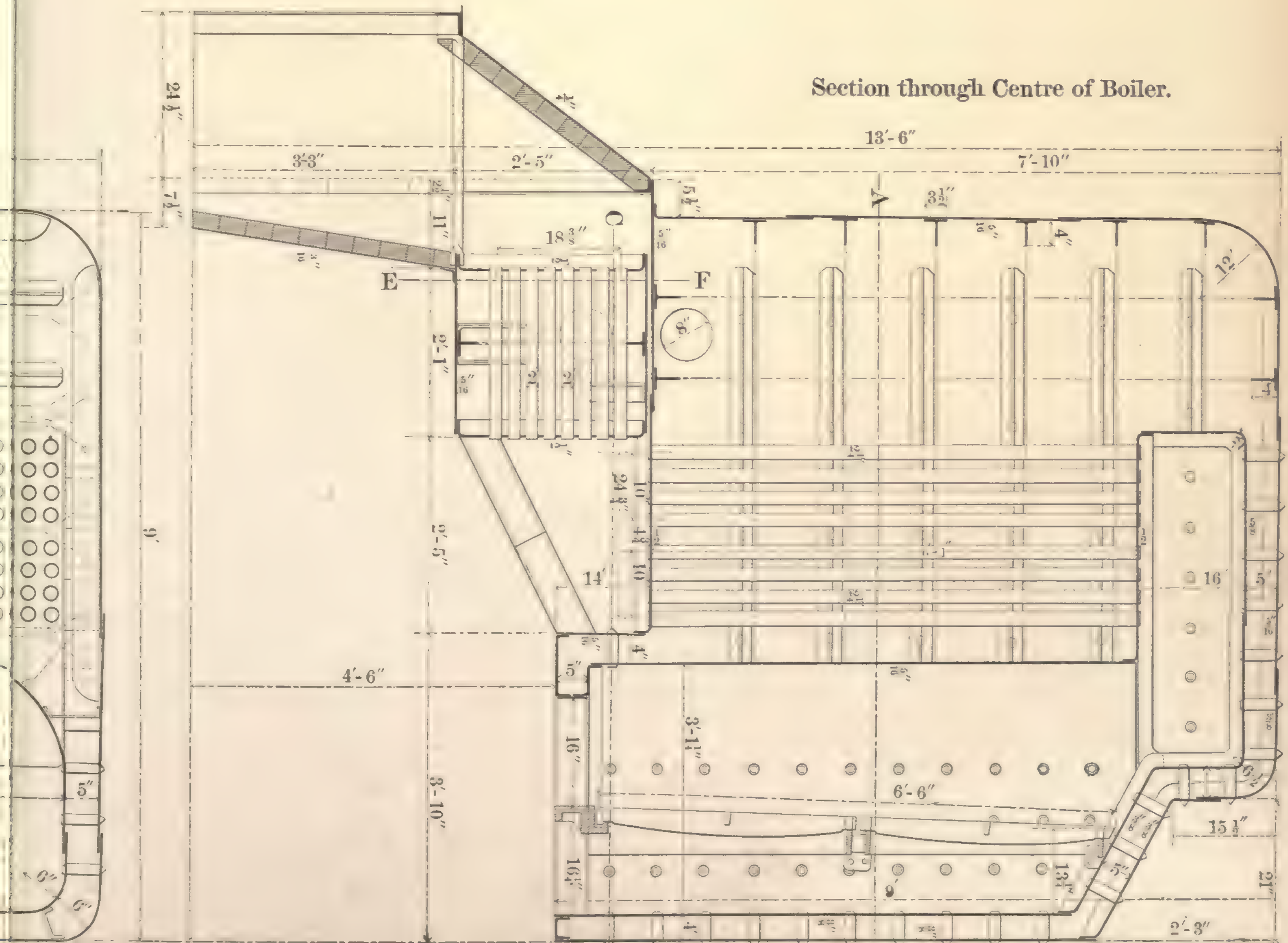
BOILERS FOR

“PLYMOUTH.”

1 2 3 Feet.



Section on E.F.



Section through Centre of Boiler.

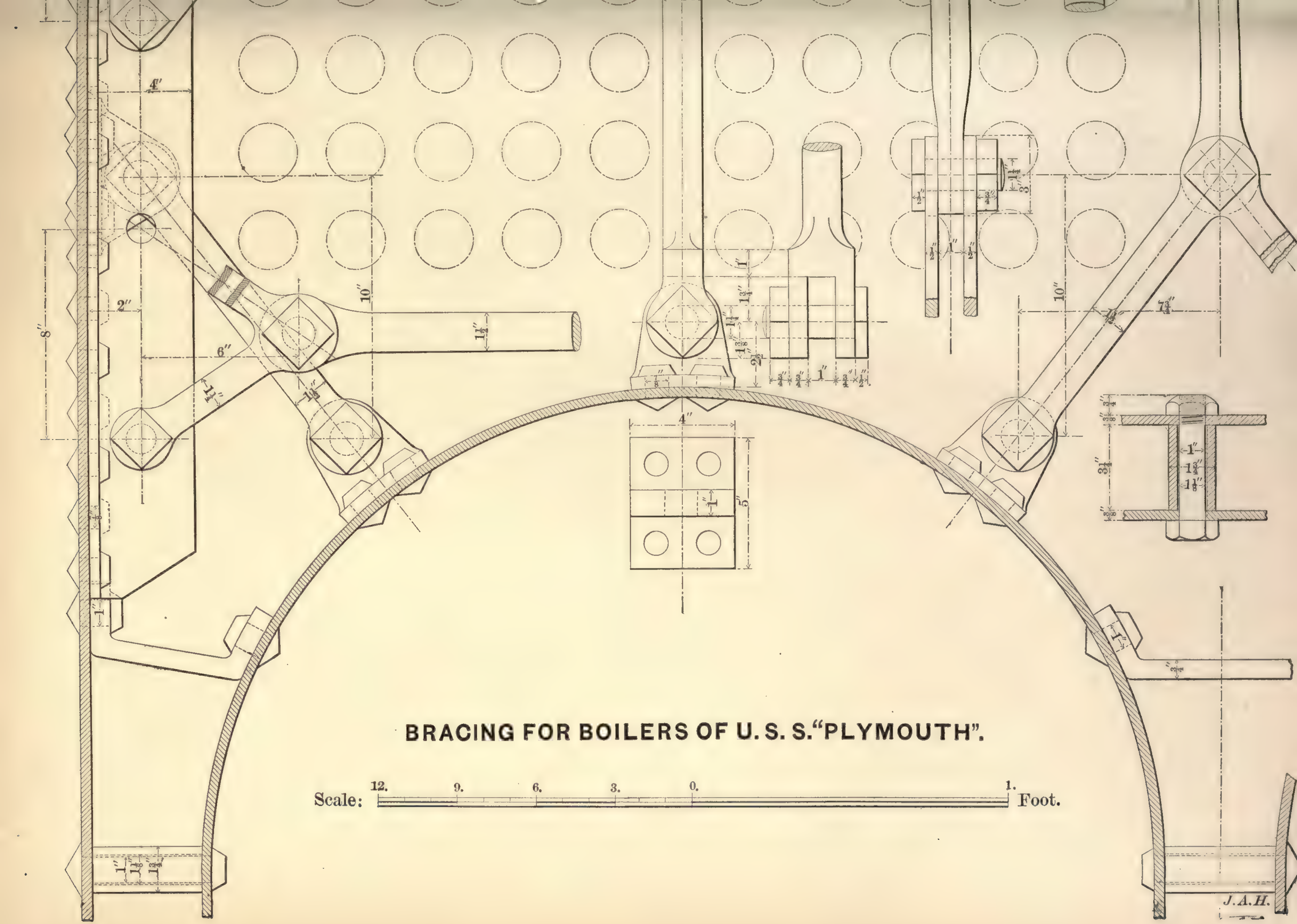
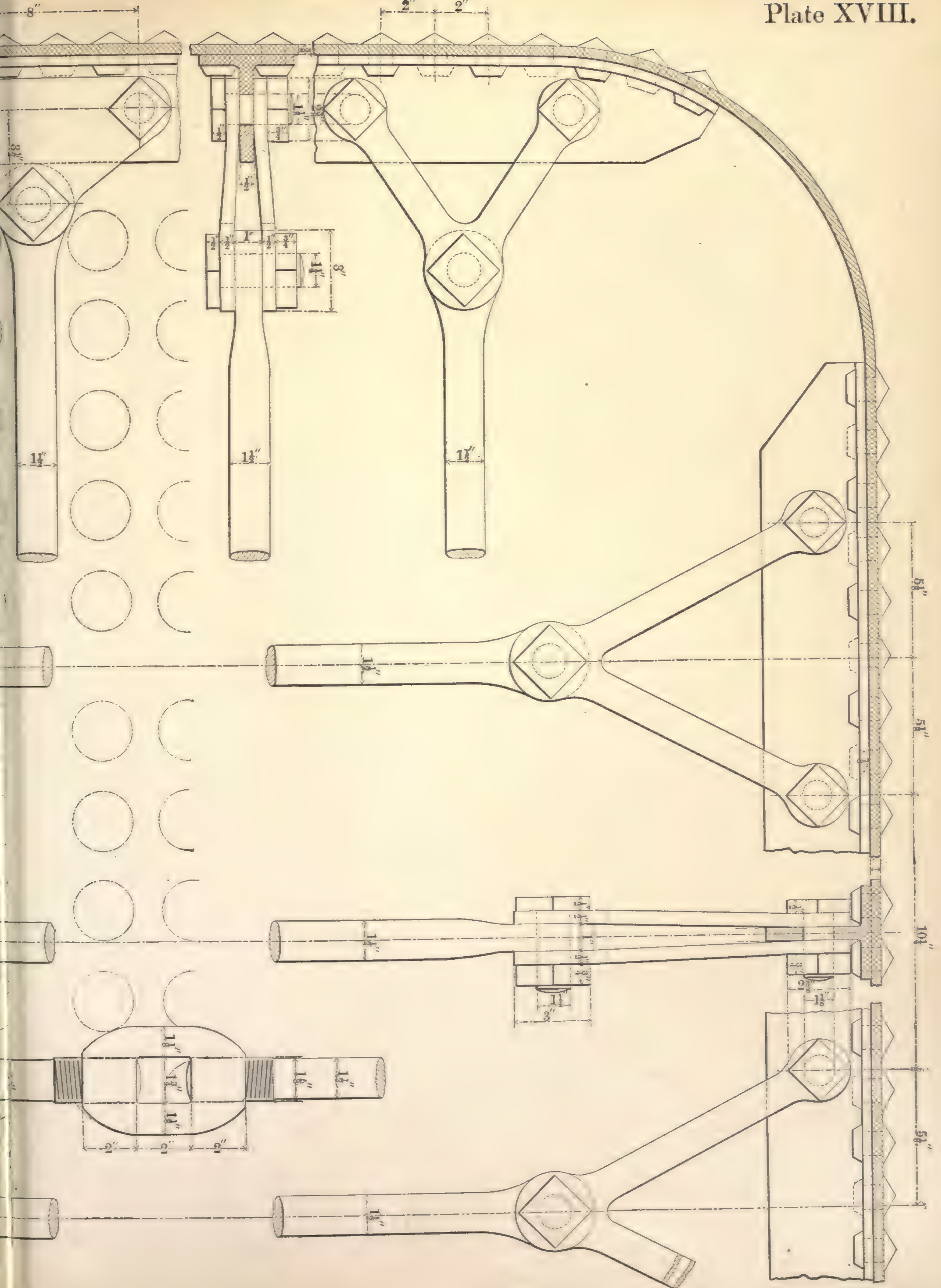

BRACING FOR BOILERS OF U. S. S. "PLYMOUTH".
Scale: 12. 9. 6. 3. 0. 1. Foot.
J. A. H.

Plate XVIII.



DETAILS FOR BOILERS OF U. S. S. "PLYMOUTH".

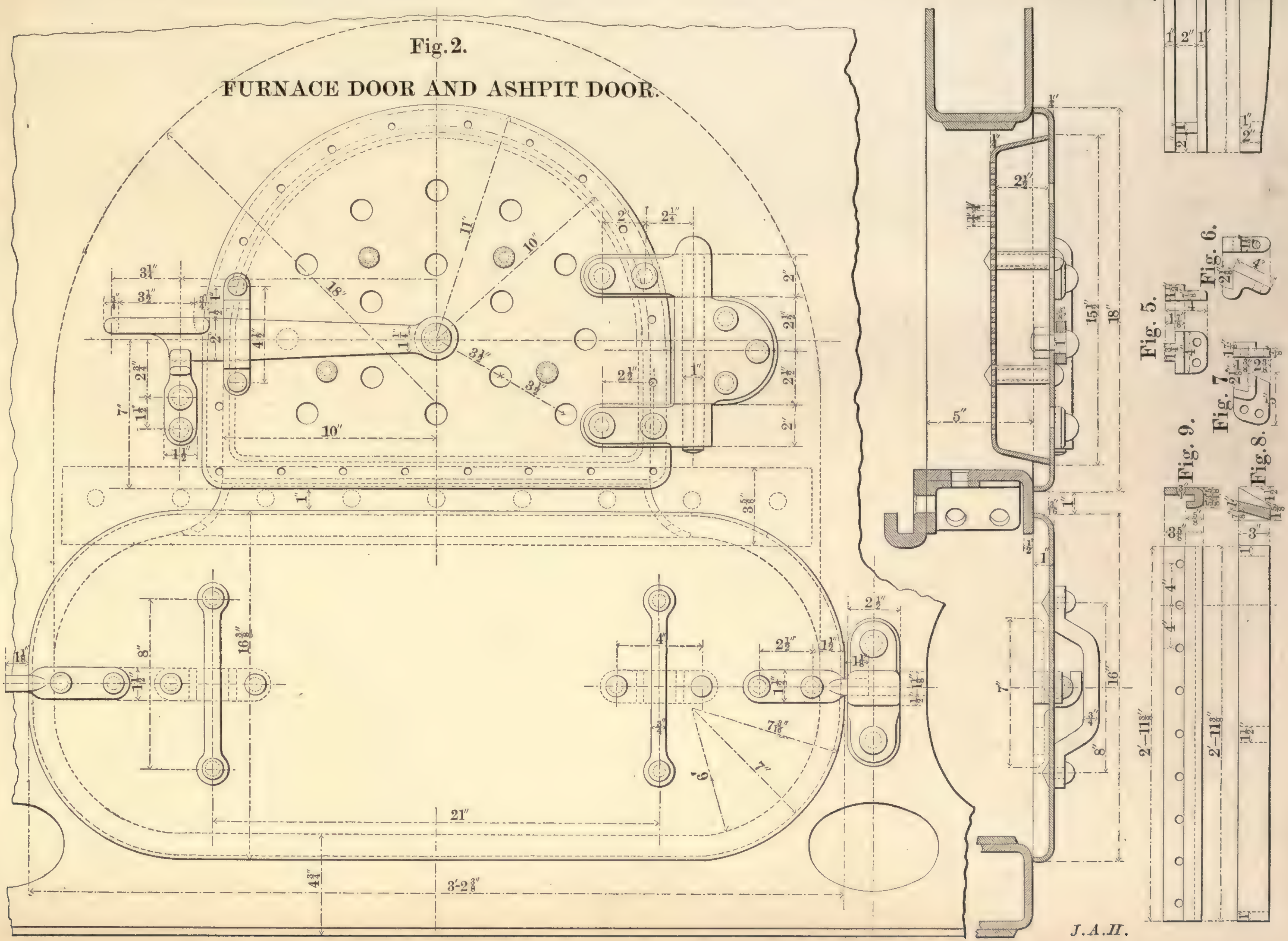


Plate XIX.

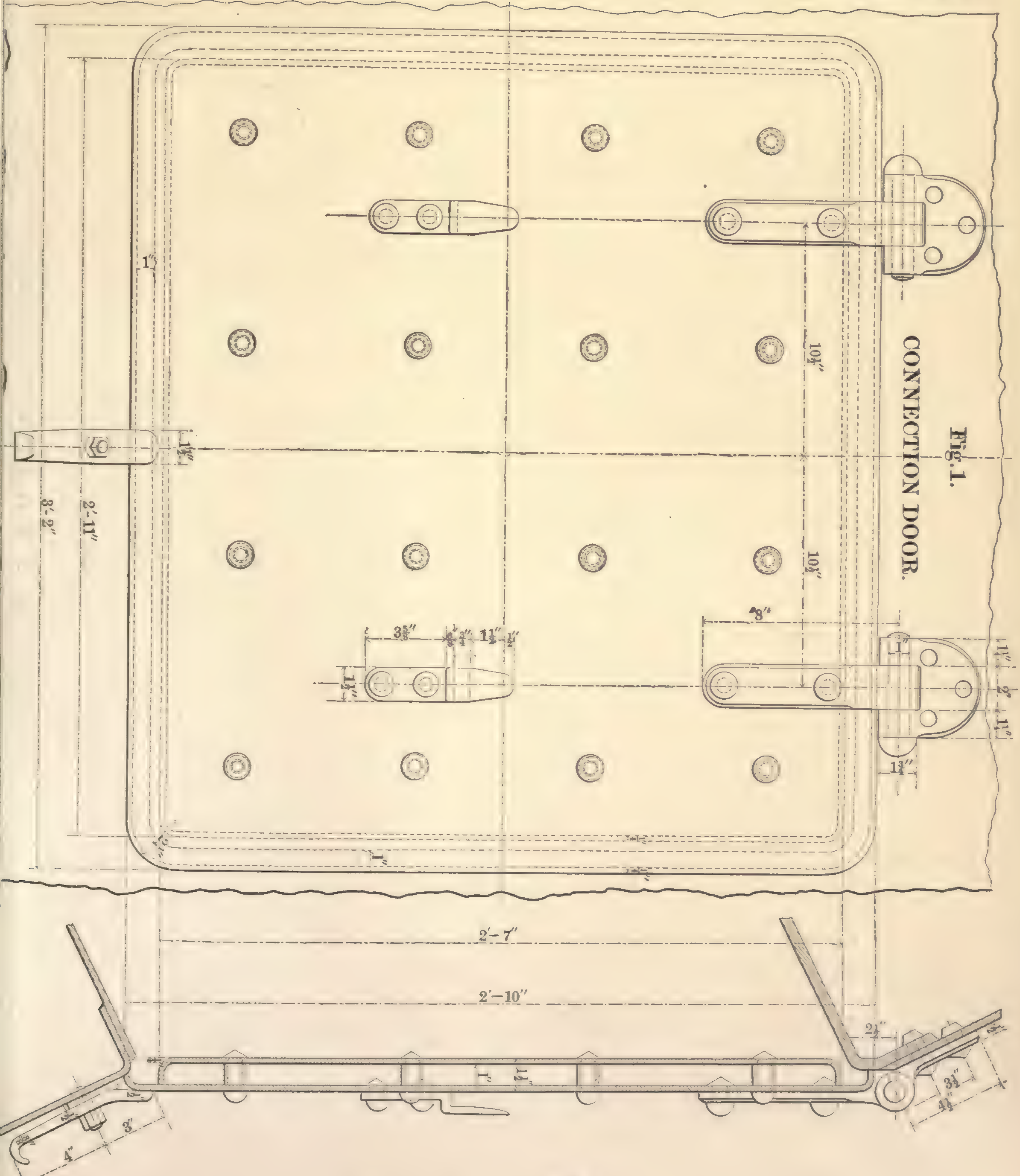
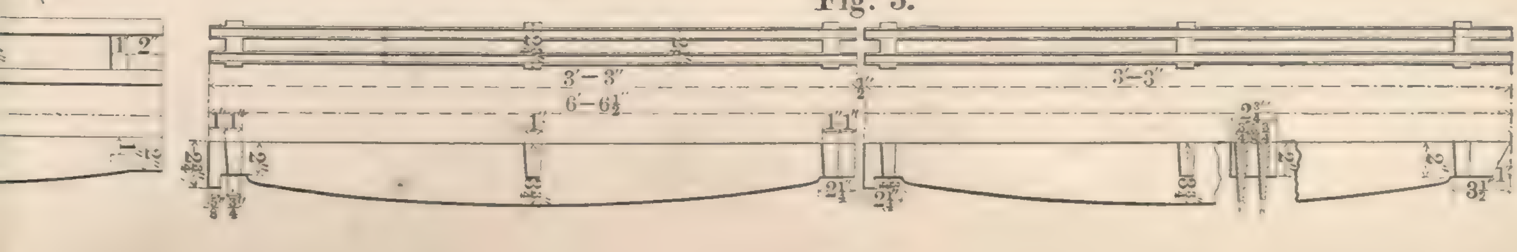
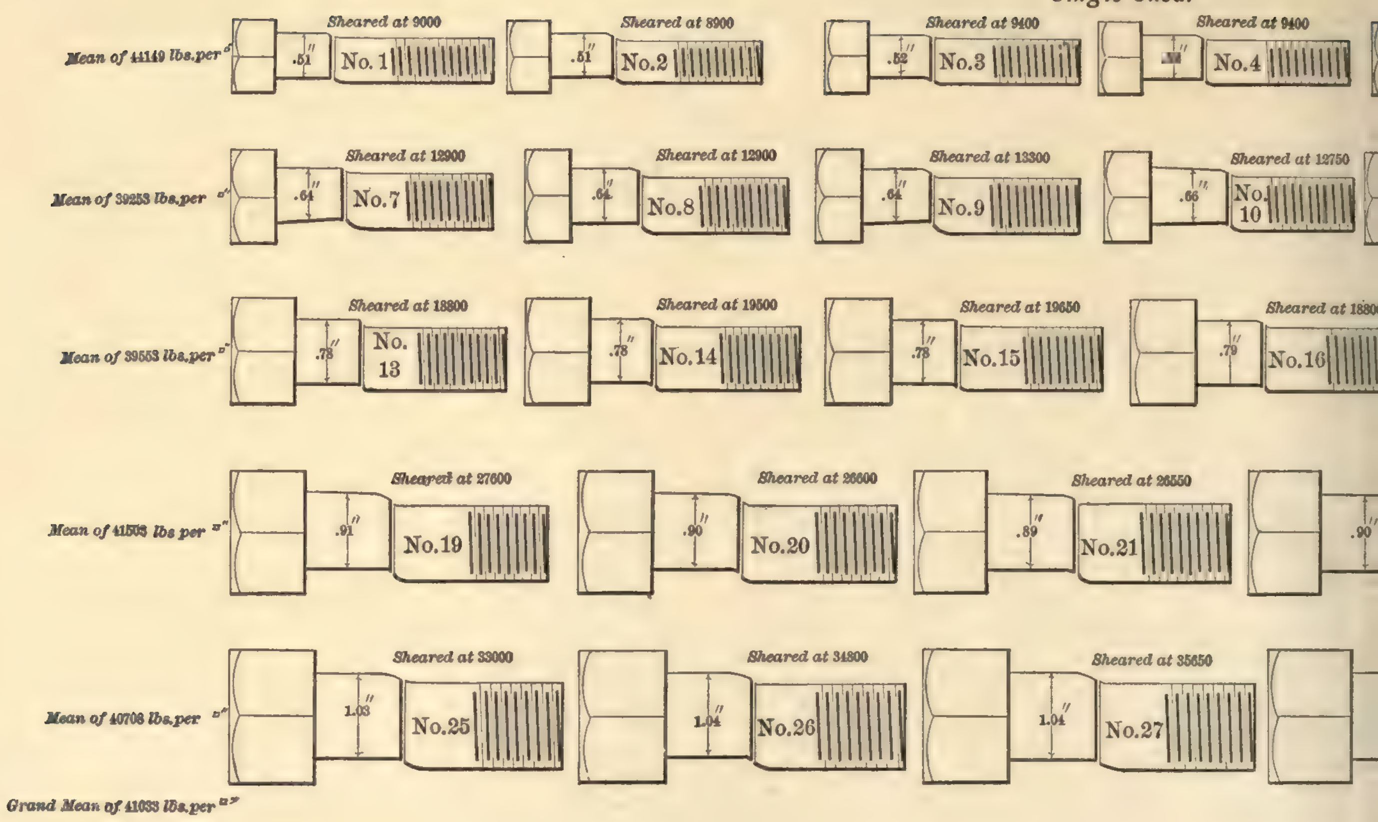


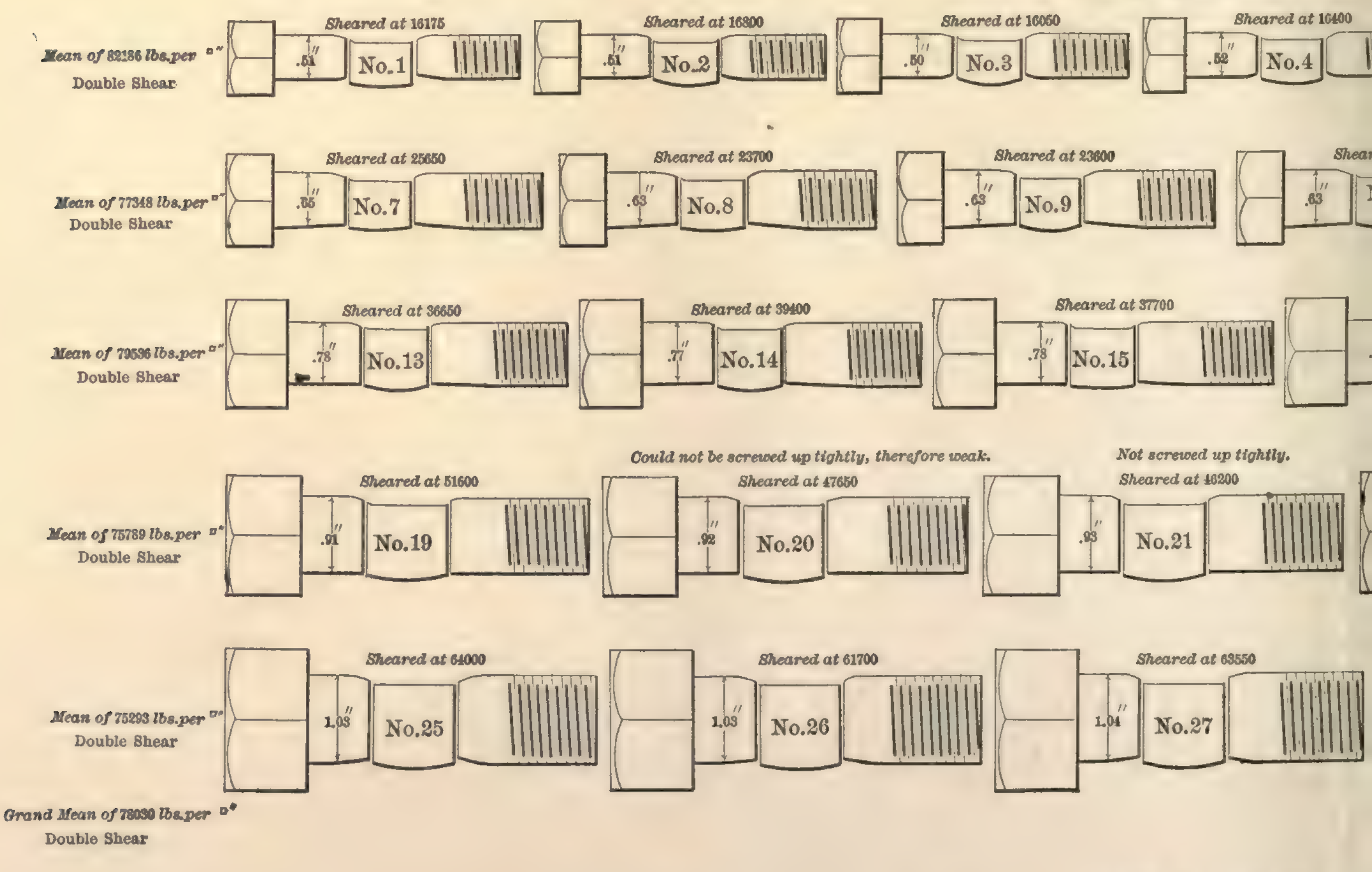
Fig. 3.



Single Shear



Double Shear



Shearing Attachment

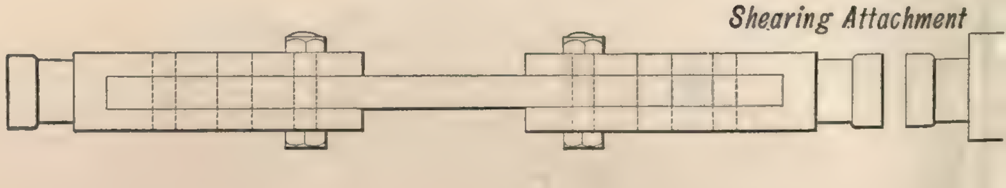


Plate XX.

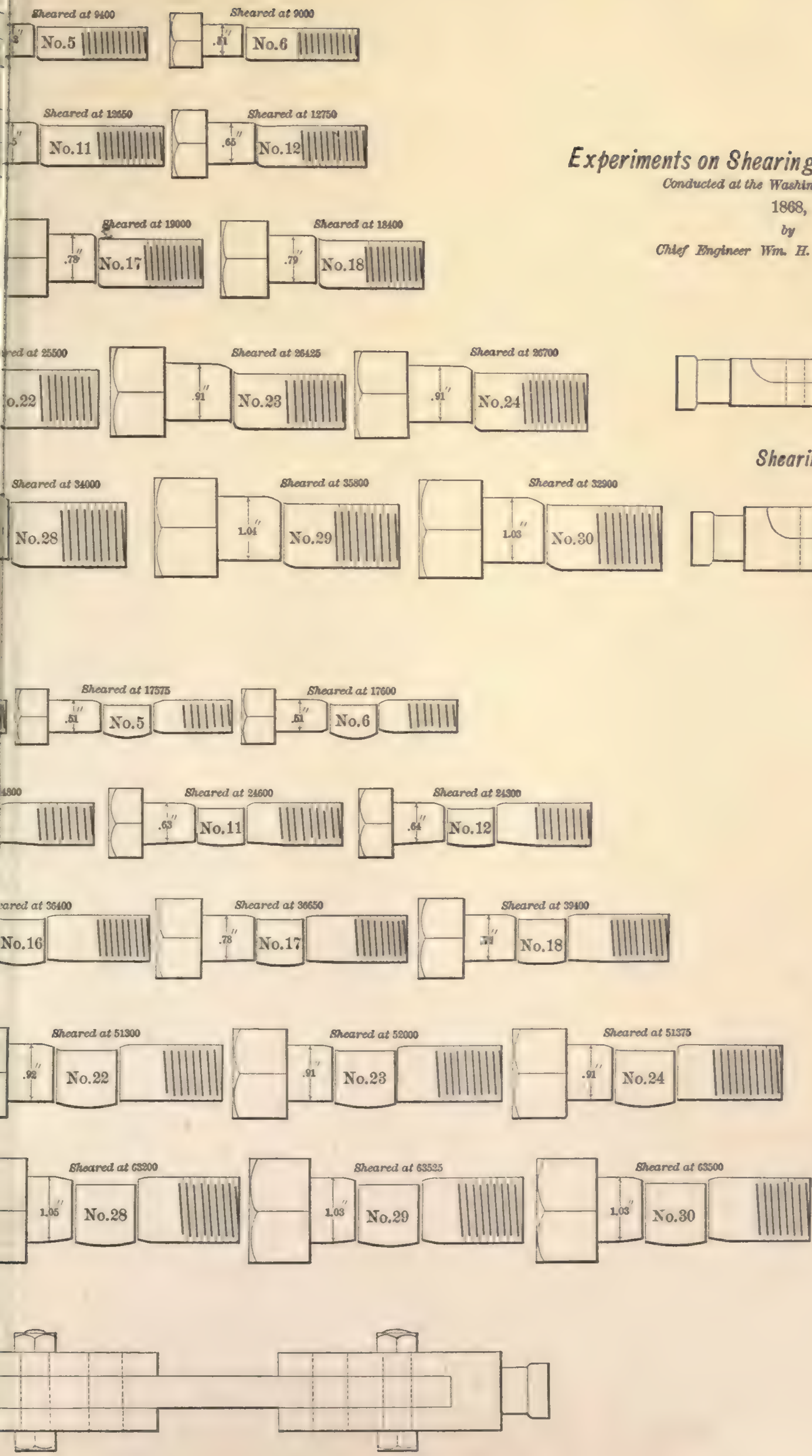
Experiments on Shearing Wrought Iron Bolts,

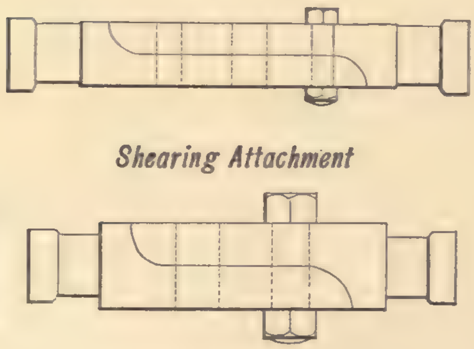
Conducted at the Washington Navy Yard,

1868,

by

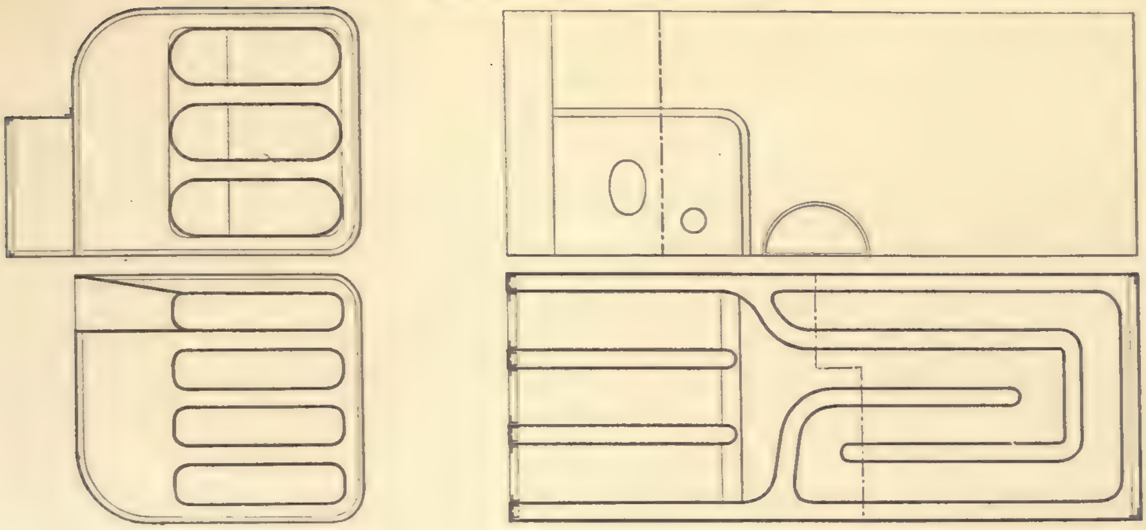
Chief Engineer Wm. H. Shock, U. S. N.





Shearing Attachment

Fig. 1.
MARINE FLUE BOILER.



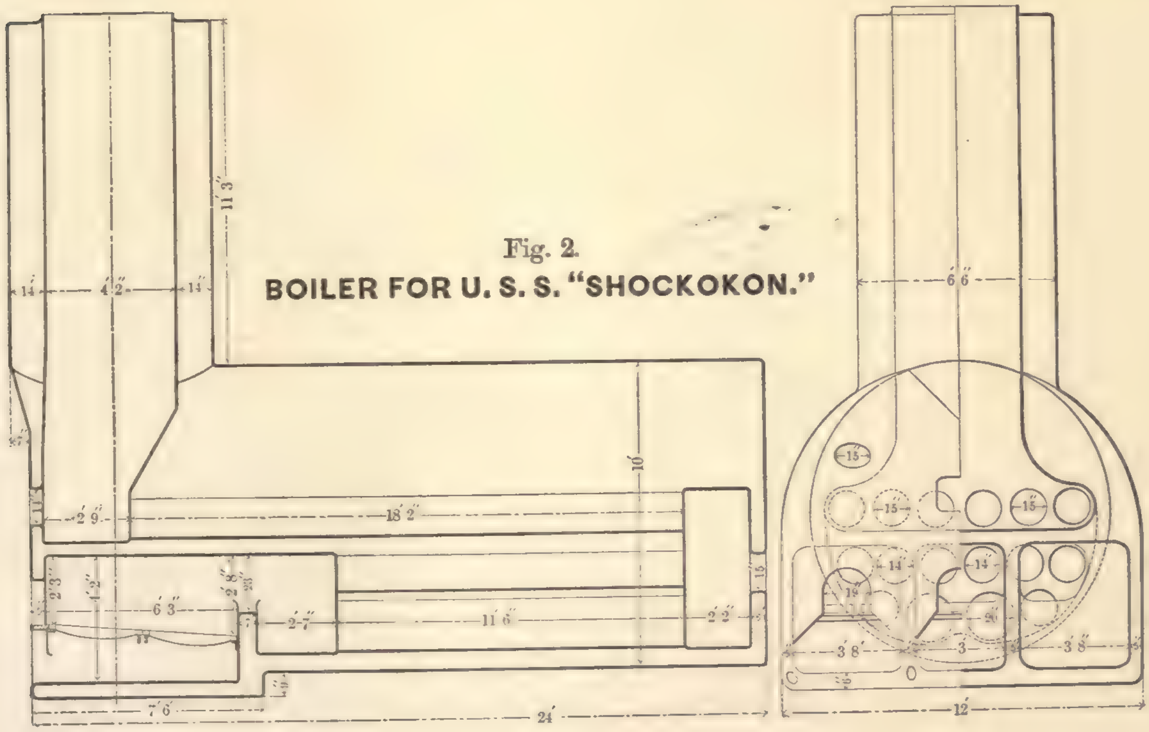


Fig. 2.
BOILER FOR U. S. S. "SHOCKOKON."

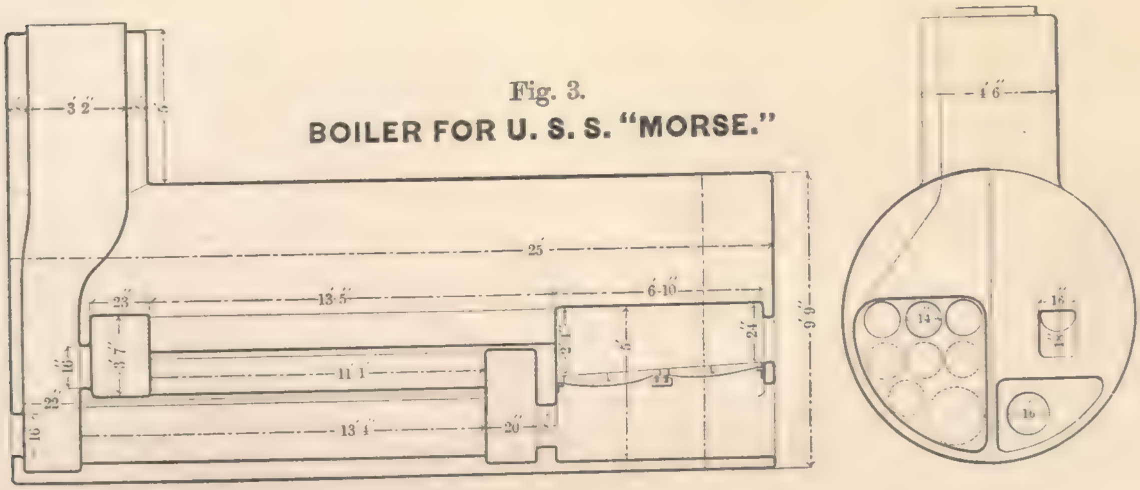


Fig. 3.
BOILER FOR U. S. S. "MORSE."

METHODS OF SECURING BOILER TUBES.

Plate XXII.

Fig. 1.

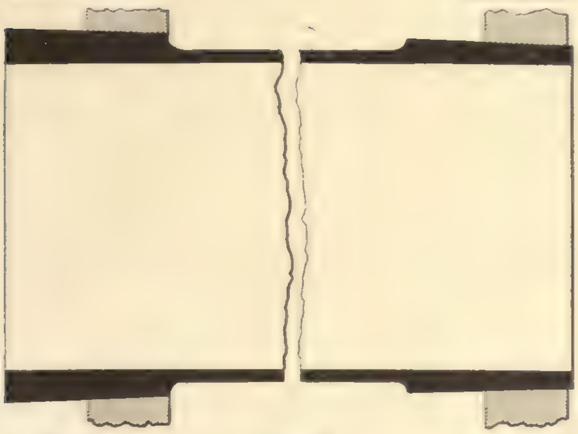


Fig. 2.

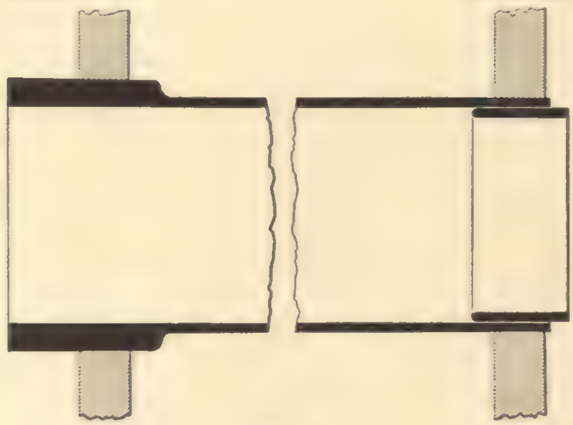


Fig. 3.

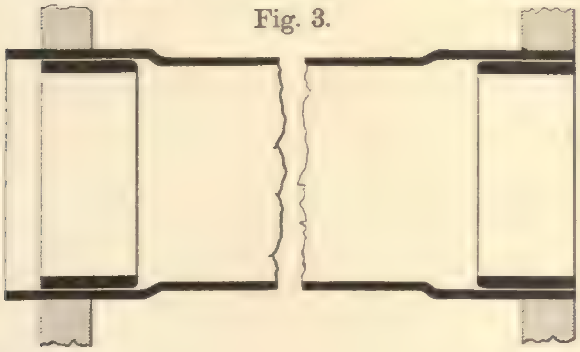


Fig. 4.

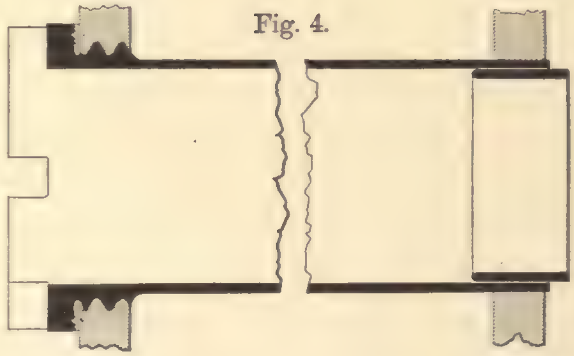


Fig. 5.

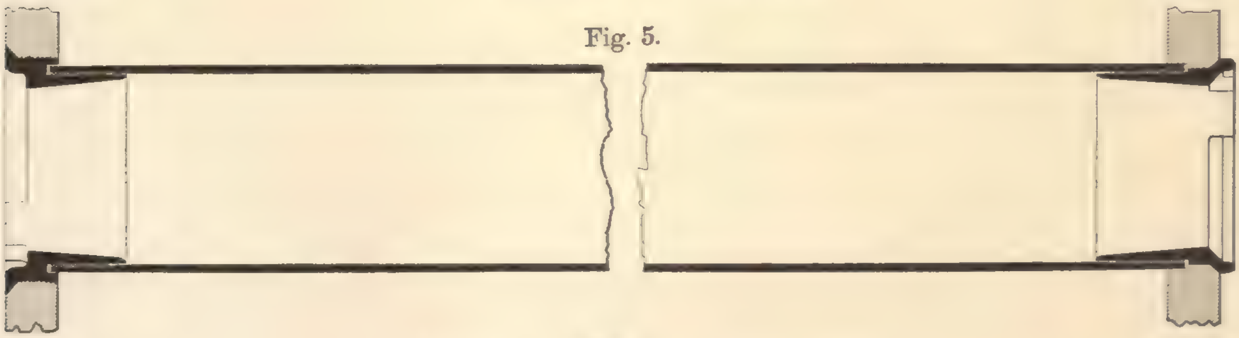


Fig. 6.

TWEDDELL'S HYDRAULIC TUBE EXPANDER.

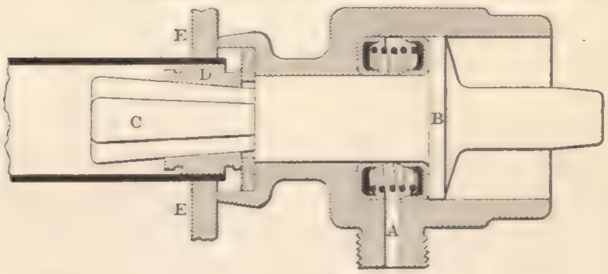
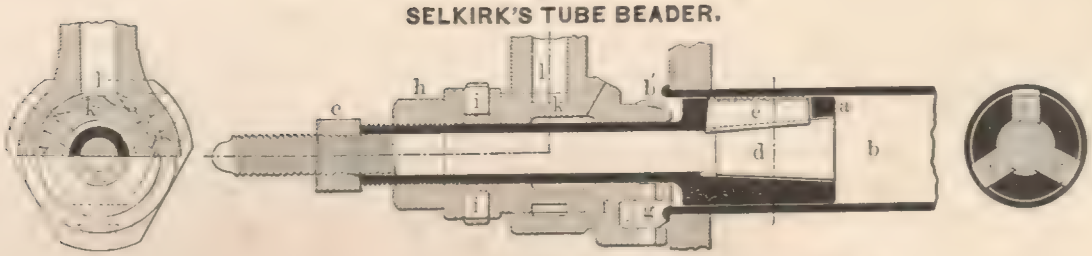
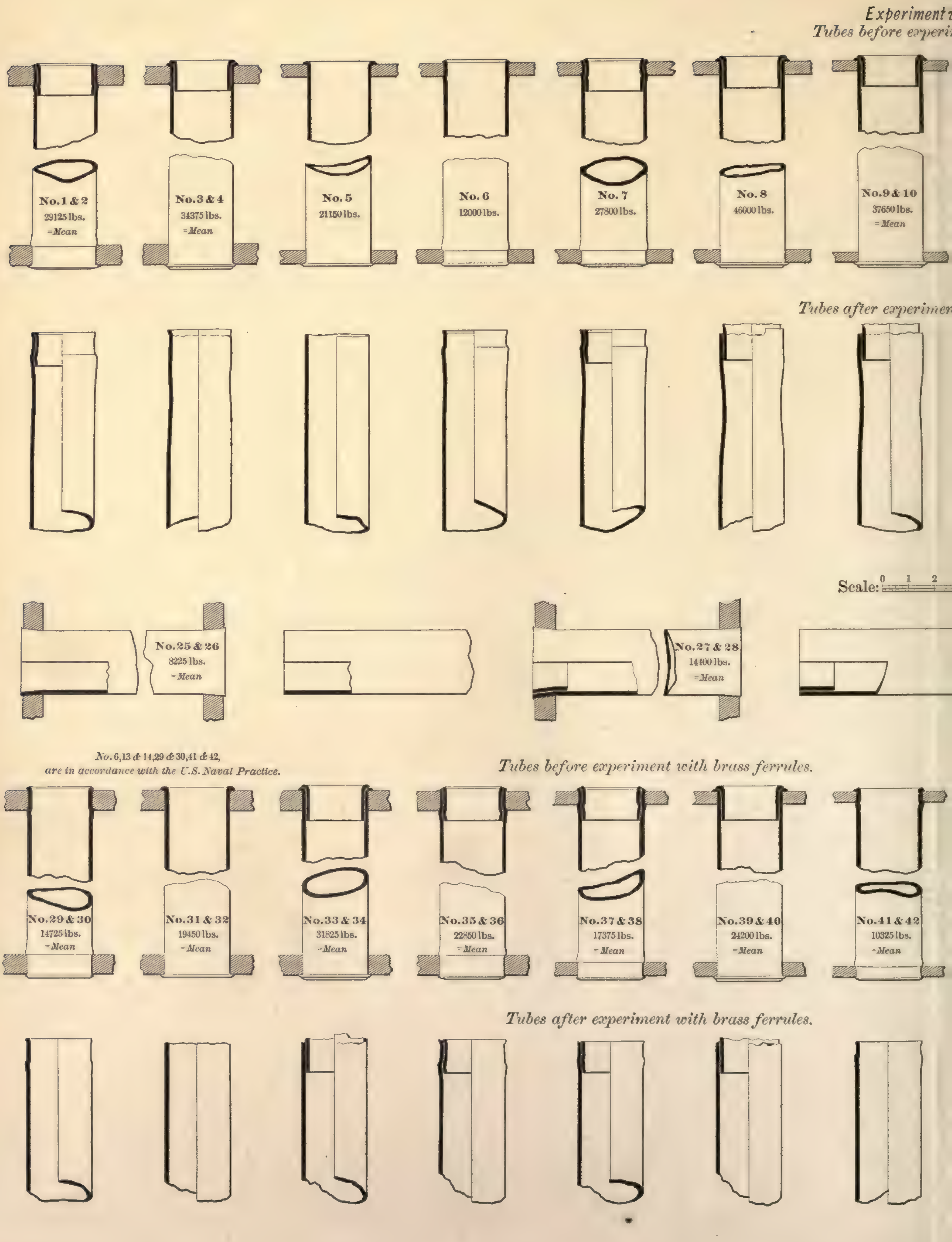


Fig. 7.

SELKIRK'S TUBE BEADER.



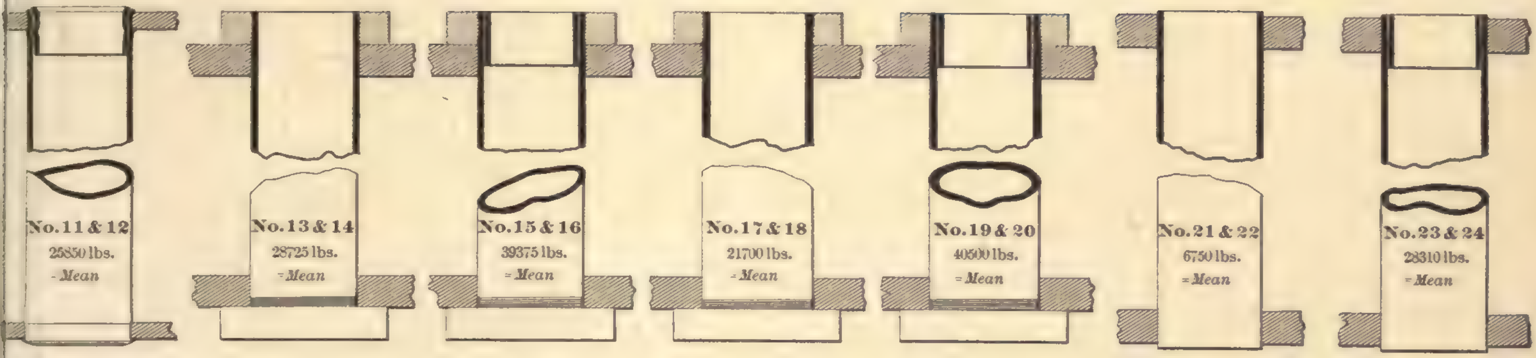


Experiment
Tubes before experi
No. 1 & 2
29125 lbs.
= Mean
No. 3 & 4
34375 lbs.
= Mean
No. 5
21150 lbs.
No. 6
12000 lbs.
No. 7
27800 lbs.
No. 8
46000 lbs.
No. 9 & 10
37650 lbs.
= Mean
Tubes after experimen
Scale: 0 1 2
No. 25 & 26
8225 lbs.
= Mean
No. 27 & 28
14400 lbs.
= Mean
No. 6, 13 & 14, 29 & 30, 41 & 42,
are in accordance with the U.S. Naval Practice.
Tubes before experiment with brass ferrules.
No. 29 & 30
14725 lbs.
= Mean
No. 31 & 32
19450 lbs.
= Mean
No. 33 & 34
31825 lbs.
= Mean
No. 35 & 36
22850 lbs.
= Mean
No. 37 & 38
17375 lbs.
= Mean
No. 39 & 40
24200 lbs.
= Mean
No. 41 & 42
10325 lbs.
= Mean
Tubes after experiment with brass ferrules.

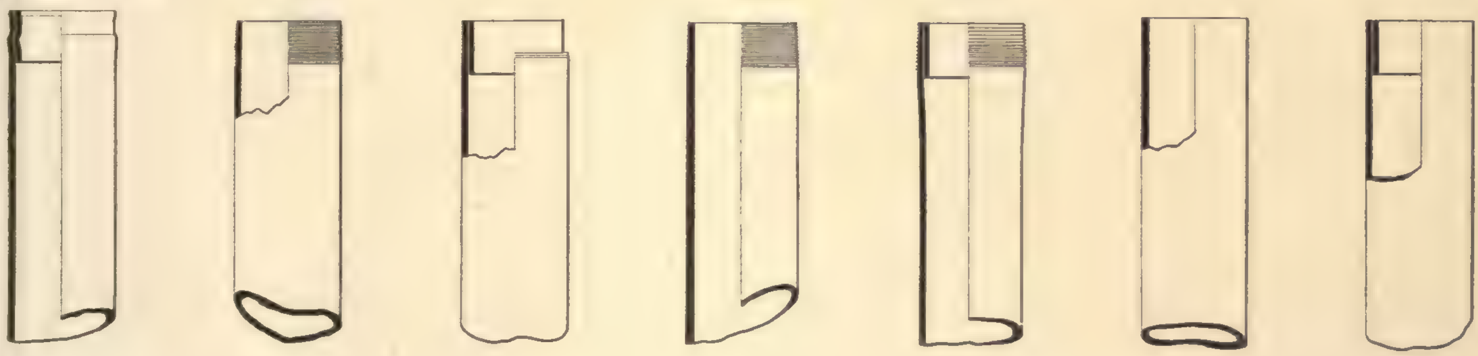
Brass Tubes.
with iron ferrules.

Composition nuts.

Plate XXIII.

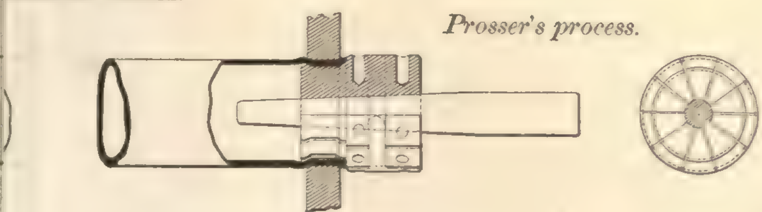


th iron ferrules,

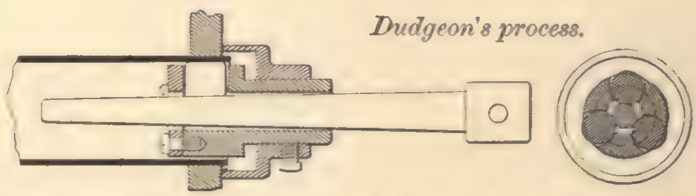


5 6 Inches.

Prosser's process.



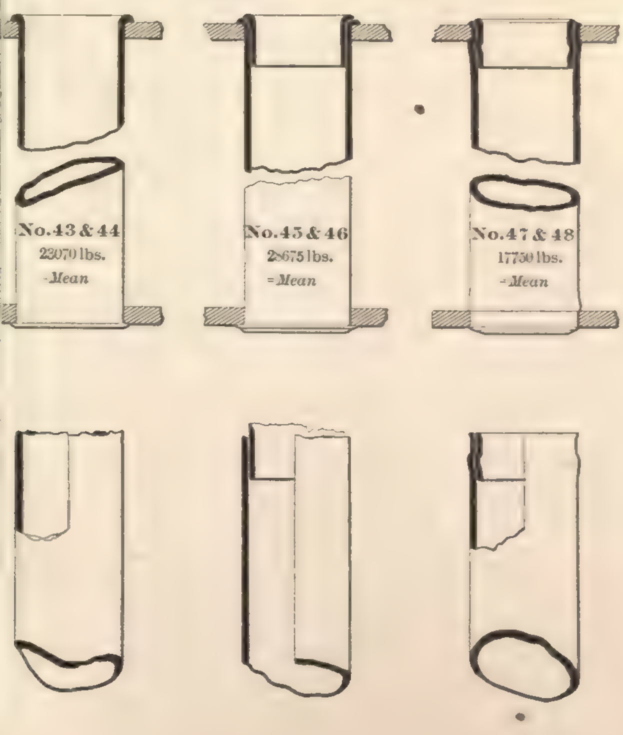
Dudgeon's process.



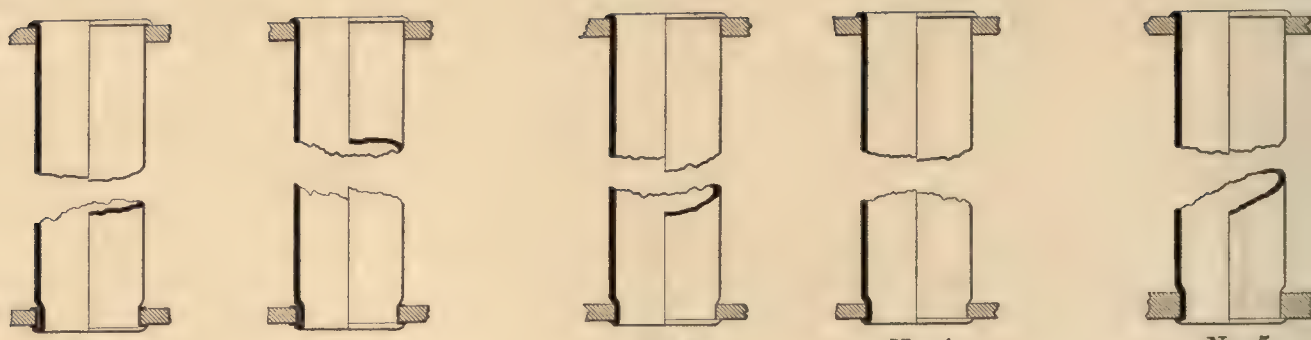
Experiments conducted at the Washington Navy Yard, Jan, 1877,
by
Chief Engineer Wm. H. Shock, U.S.N.

Number of Specimen	Outside Diameter	Area of section of tube	Diameter after expanding	Thickness of tube plate	Method of fastening	Kind of ferrule	Temperature Fahr.	Strain in pounds
1	2.5	.9	2.42	3/4	Prosser	Iron	78	28050
2	"	"	2.41	"	"	"	"	30200
3	"	"	2.35	"	Dudgeon	"	70	32750
4	"	"	2.34	"	"	"	"	36000
5	"	"	2.50	1/2	"	None	70	21150
6	"	"	2.44	"	Prosser	"	71	12000
7	"	"	"	"	"	Iron	"	27800
8	"	"	2.25	"	Dudgeon	"	"	46000
9	"	"	2.31	3/8	"	"	72	39300
10	"	"	2.44	"	"	"	"	36000
11	"	"	2.50	"	Prosser	"	"	25300
12	"	"	"	"	"	"	–	26400
13	"	"	"	3/4	Nut 1/4 thick	None	78	30450
14	"	"	"	"	"	"	"	27000
15	"	"	"	"	"	Iron	–	40150
16	"	"	"	"	"	"	–	38600
17	2.6	1.33	2.60	"	"	None	"	22000
18	"	"	"	"	"	"	"	21400
19	"	"	"	"	"	Iron	"	39350
20	"	"	2.40	"	"	"	"	41650
21	2.5	.9	2.50	"	Dudgeon	None	65	7650
22	"	"	"	"	"	"	"	5850
23	"	"	"	"	"	Iron	64½	14460
24	"	"	"	"	"	"	"	13850

Number of Specimen	Outside Diameter	Area of section of tube	Diam. after experiment	Thickness of tube plate	Method of fastening	Kind of ferrule	Temperature Fahr.	Strain in pounds
25	2.5	.9	2.5	3/4	Dudgeon	None	–	8300
26	"	"	"	"	"	"	–	8150
27	"	"	"	"	"	Iron	–	[illegible]
28	"	"	"	"	"	"	–	[illegible]
29	"	"	"	"	Prosser	None	75	14450
30	"	"	"	"	"	"	"	15000
31	"	"	"	"	Dudgeon	"	"	17075
32	"	"	"	"	"	"	"	21825
[illegible]	"	"	"	"	"	Brass	"	32250
34	"	"	"	"	"	"	"	31400
35	"	"	"	"	Prosser	"	"	22750
[illegible]	"	"	"	"	"	"	"	22950
37	"	"	"	1/2	"	"	70	17850
38	"	"	"	"	"	"	"	17400
39	"	"	"	"	Dudgeon	"	"	24800
40	"	"	"	"	"	"	"	23600
41	"	"	"	3/8	Prosser	None	75	9800
42	"	"	"	"	"	"	"	10850
43	"	"	"	"	Dudgeon	–	–	23890
44	"	"	"	"	"	"	"	22250
45	"	"	"	"	"	Brass	"	29800
46	"	"	"	"	"	"	"	27550
47	"	"	"	"	Prosser	"	"	15250
48	"	"	"	"	"	"	"	20250

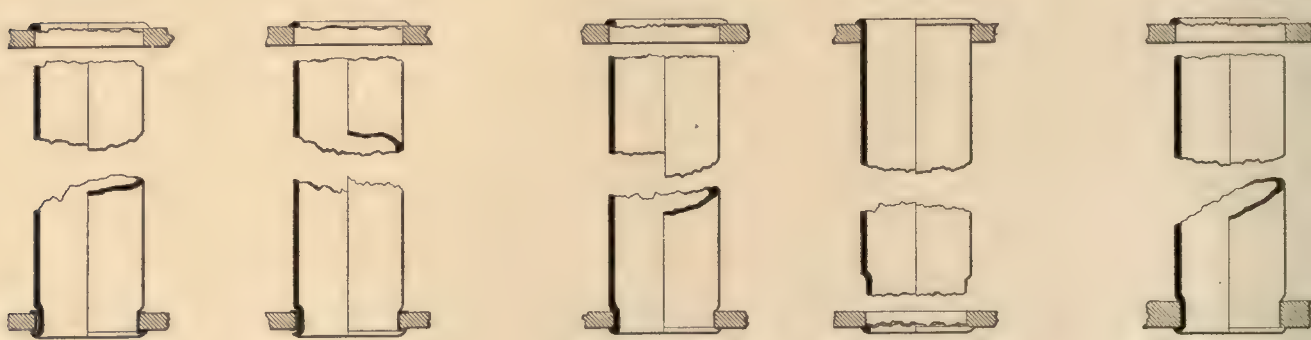


Tubes bef

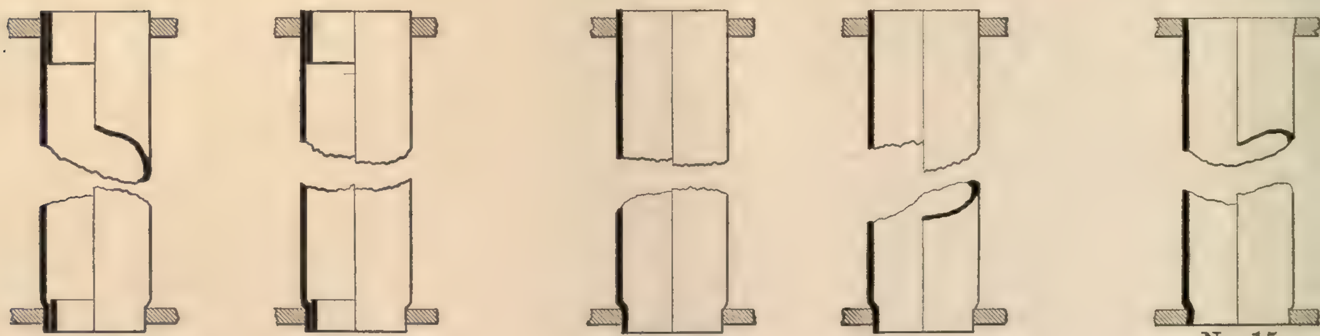


No. 1 29050 lbs. | No. 2 19950 lbs. | No. 3 26900 lbs. | No. 4 25525 lbs. | No. 5 20250 lbs.

Tubes a

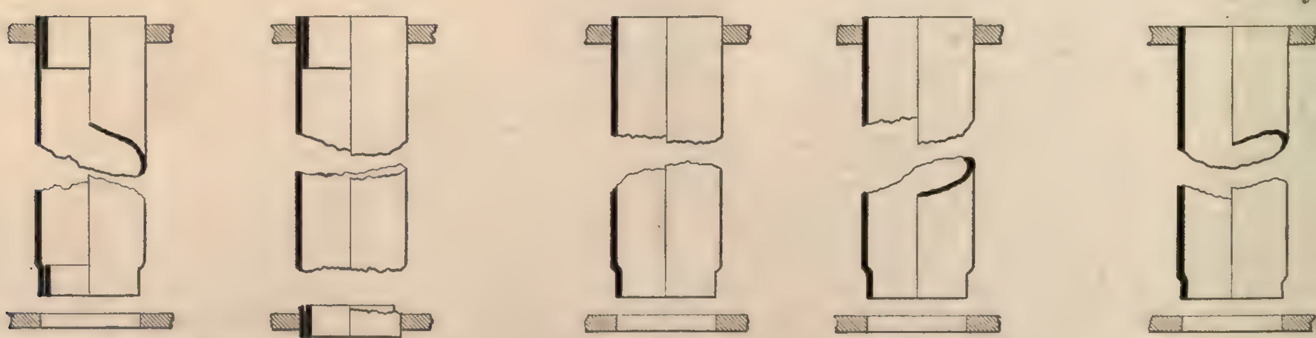


Tubes bef



No. 11 29700 lbs. | No. 12 29650 lbs. | No. 13 11300 lbs. | No. 14 14800 lbs. | No. 15 8850 lbs.

Tubes af



RUSSELL & STRUTHERS, ENG'S, N.Y.

Plate XXIV

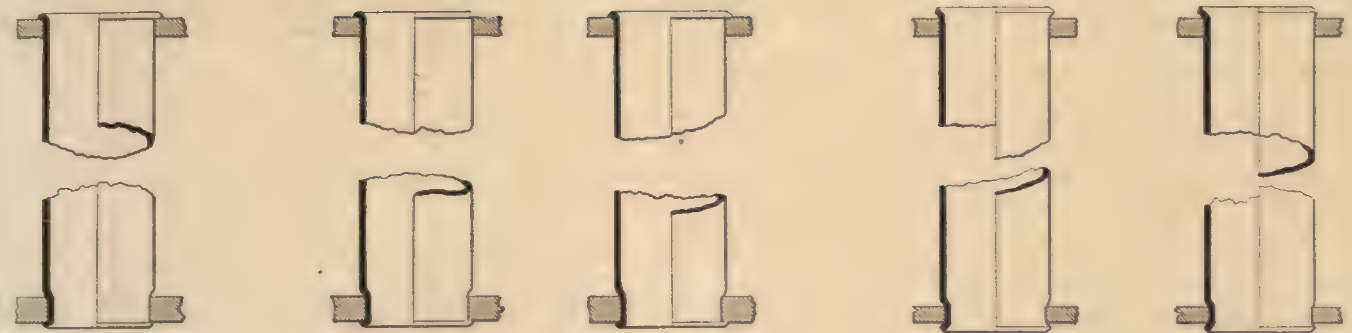
Experiment with Iron Tubes, with Copper, Iron & Steel tube plates.

Conducted at the Washington Navy Yard, Jan. 1877.

by

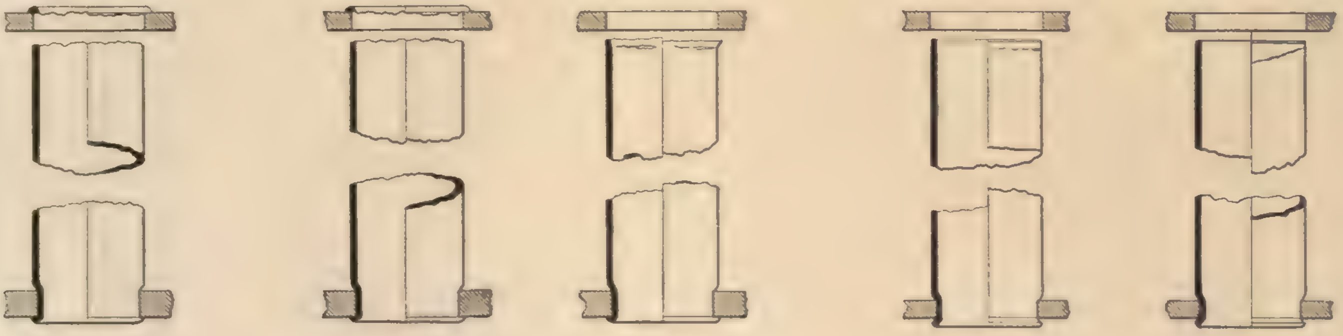
Chief Engineer Wm. H. Shock, U. S. N.

experiment.

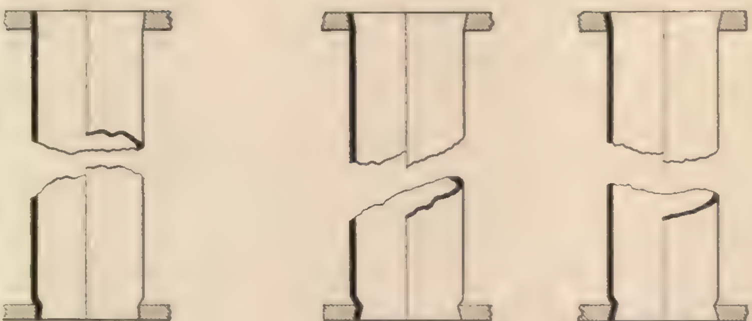


No. 6 17300 lbs. | No. 7 20450 lbs. | No. 8 24650 lbs. | No. 9 22700 lbs. | No. 10 21600 lbs.

experiment.

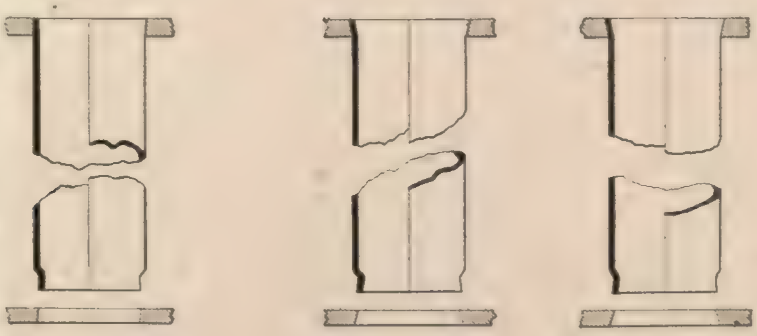


experiment.

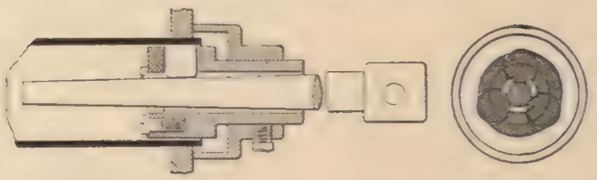


No. 16 5950 lbs. | No. 17 22100 lbs. | No. 18 17550 lbs.

experiment.



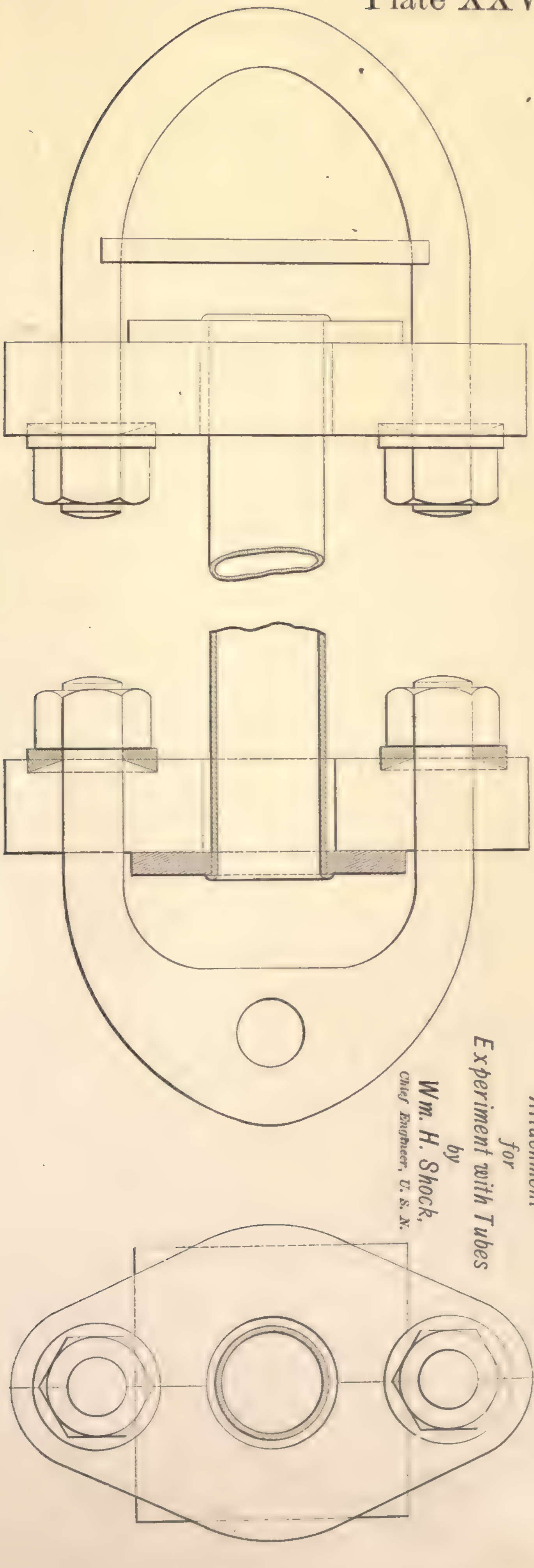
Tubes expanded by Dudgeon's process.



Scale: 0 1 2 3 4 5 6 Inches.

Number of specimen.	Outside diameter.	Outside diameter of small end.	Area of section of tube.	Diameter after experiment.	Material & thickness. Upper tube-plate.		Lower tube-plate.		Method of fastening.	Temperature, Fahr.	Strain in pounds.
	Ins.	Ins.	Sq. in	Ins.		In.		In.			
1	2⅝	[illegible]	.981	2⅝	Iron	7-16	Steel.	⅜	Copper ring in lower tube-plate. Ends of tube riveted over.	68½°	29050
2	"	"	"	"	"	"	"	"	" " "	"	19950
3	"	"	"	"	"	"	"	"	Riveted over.	"	26900
4	"	"	"	"	"	"	"	"	" "	"	25525
5	"	"	"	"	"	"	Copp	⅝	" "	"	20250
6	"	"	"	"	"	"	"	"	" "	"	17300
7	"	"	"	"	"	"	"	"	" "	"	20450
8	"	"	"	"	"	"	"	"	" "	"	24650
9	"	"	"	"	"	"	Steel	⅜	Partly riveted.	"	22700
10	"	"	"	"	"	"	"	"	" "	"	21600
11	"	"	"	2 9-16	"	"	"	"	Iron ferrules.	"	26700
12	"	"	"	"	"	"	"	"	" "	"	29050
13	"	"	"	2⅝	"	"	"	"	Simply expanded.	"	11300
14	"	"	"	"	"	"	"	"	" "	"	14800
15	"	"	"	"	"	"	"	"	Tube-plate holes taper 2⅝ × 2 11-16 and 2⅜ × 2 7-16.	"	8850
16	"	"	"	"	"	"	"	"	" " "	"	5950
17	"	"	"	2 9-16	"	"	"	"	Tube-plate holes taper 2⅝ × 2 13-16 and 2⅜ × 2 9-16	71°	22100
18	"	"	"	2⅝	"	"	"	"	" " "	"	17550

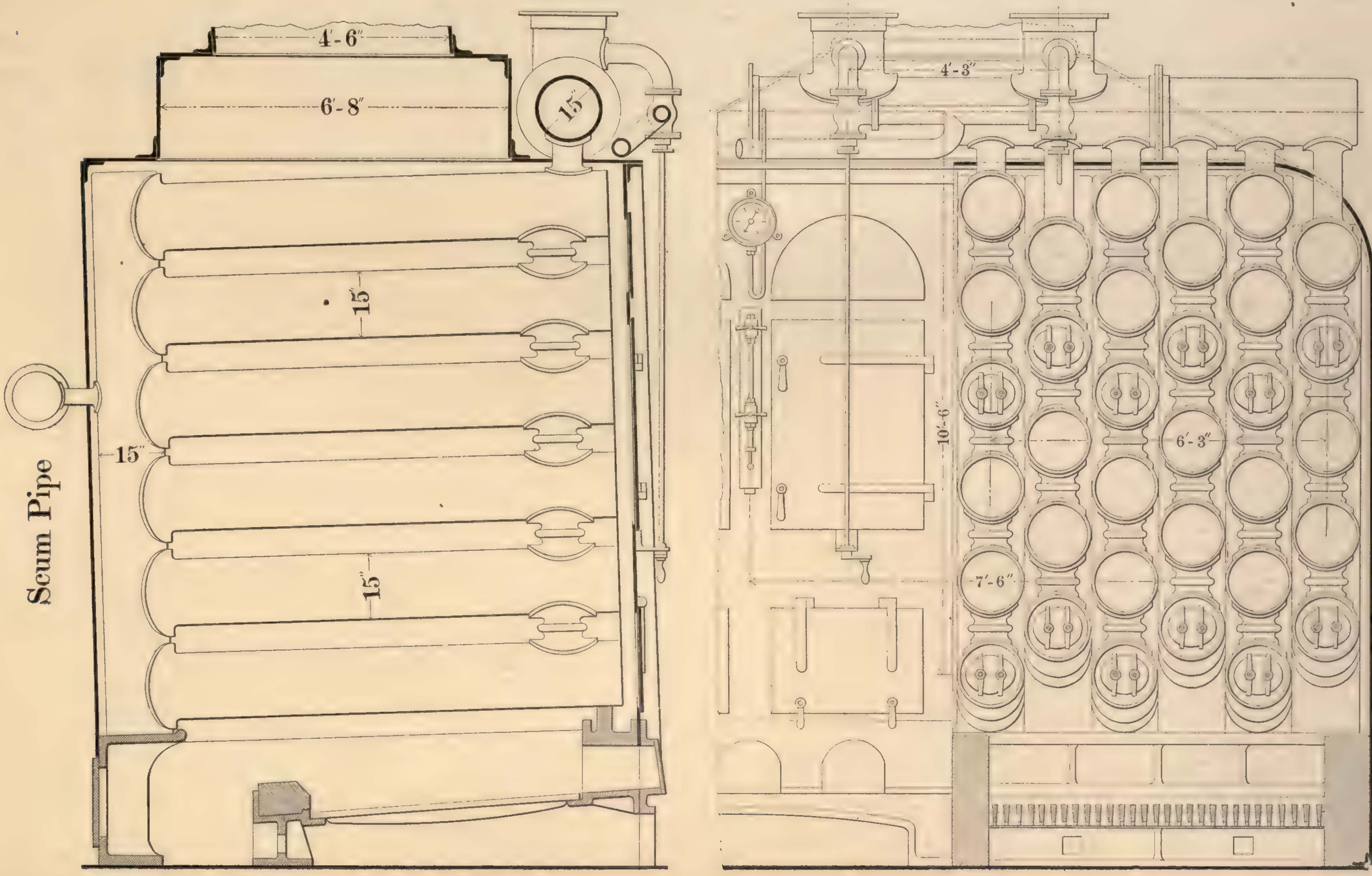
Plate XXV.



Attachment
for
Experiment with Tubes
by
Wm. H. Shock,
Chief Engineer, U. S. N.

Fig. 2.

MARINE BOILER BY T. & F. HOWARD.



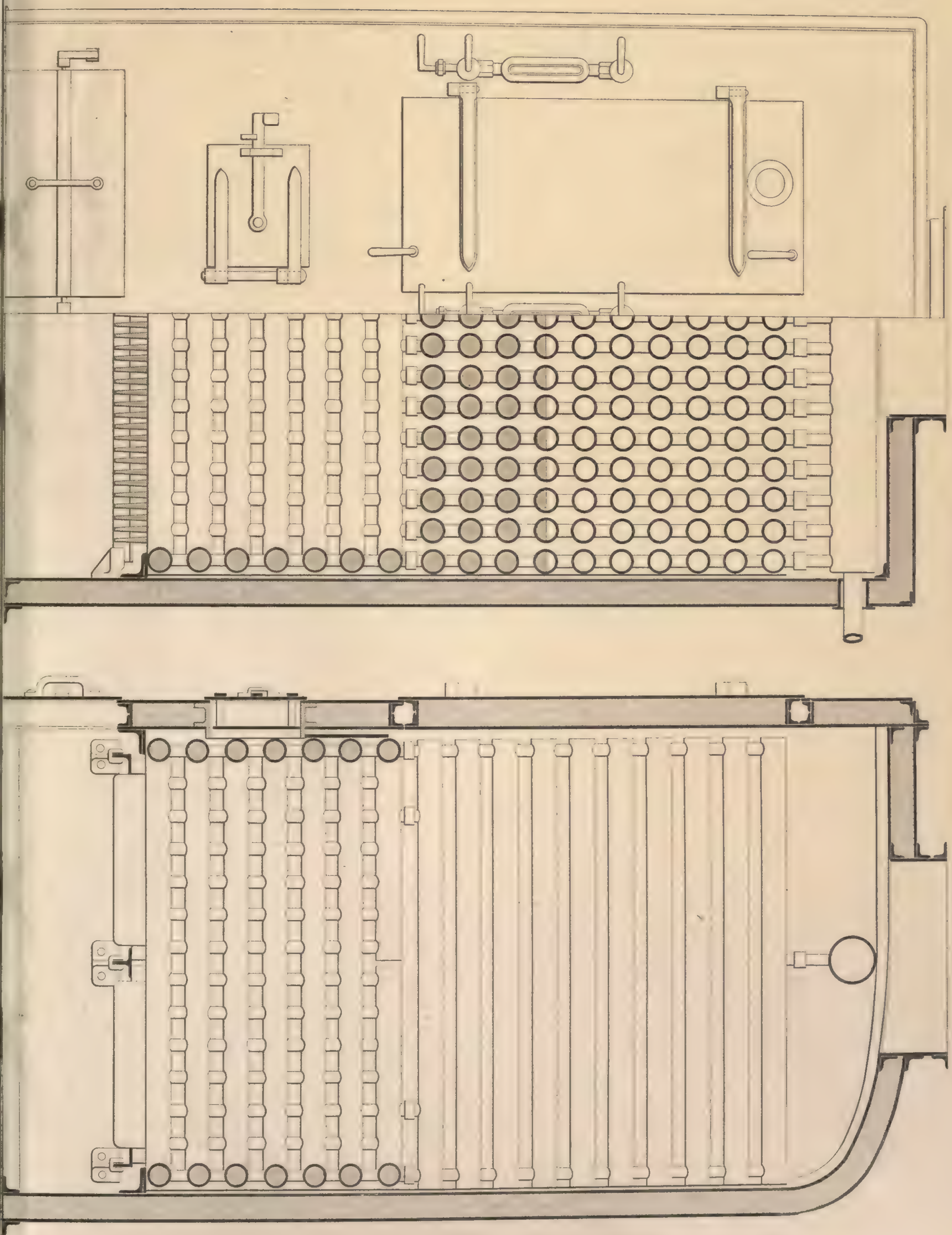


Fig. 1.

THE PERKINS TUBULAR BOILER.

Fig. 1.

THE HERRESHOFF COIL BOILER.

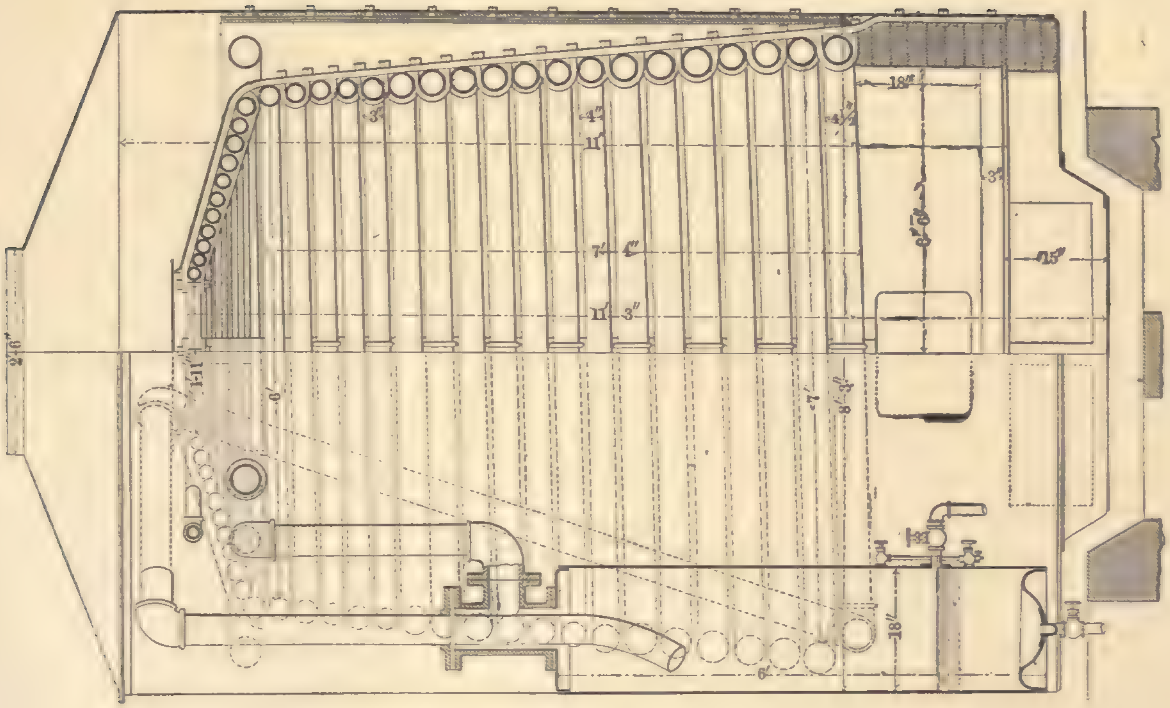


Fig. 2.

THE BELLEVILLE BOILER.

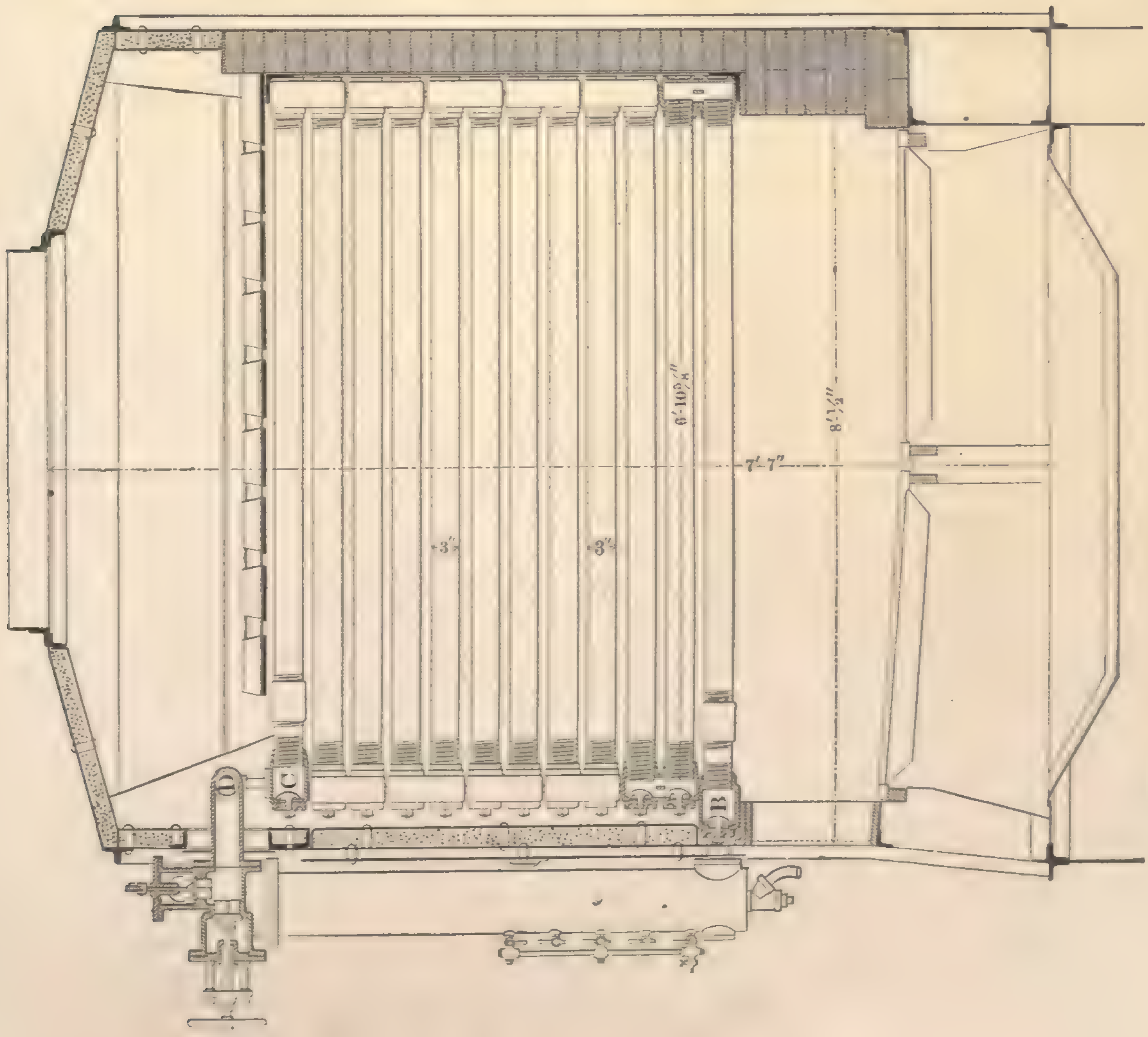


Plate XXVIII.

Fig. 1.

BOILER FOR 8"X8" ENGINE, U. S. S. CUTTERS.

Grate-surface-5.33 sq.ft.
Steam-Room-4.10 cub.ft.
Heating-surface-150 sq.ft.
Weight of Boiler-2110 lbs.

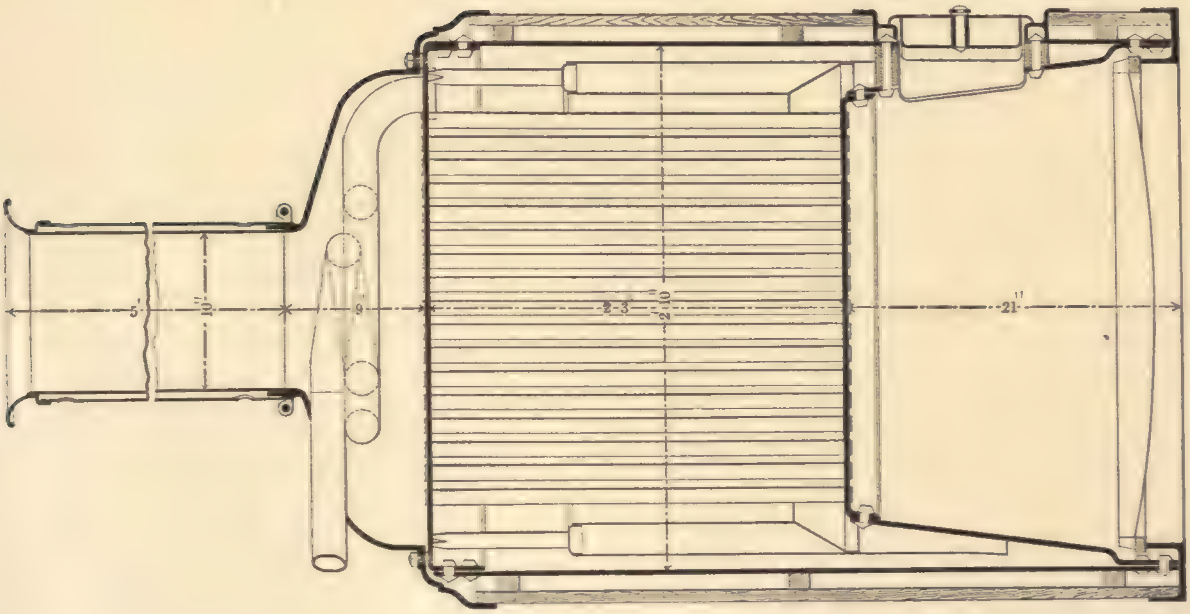


Fig. 2.

THE DAVEY-PAXMAN BOILER.

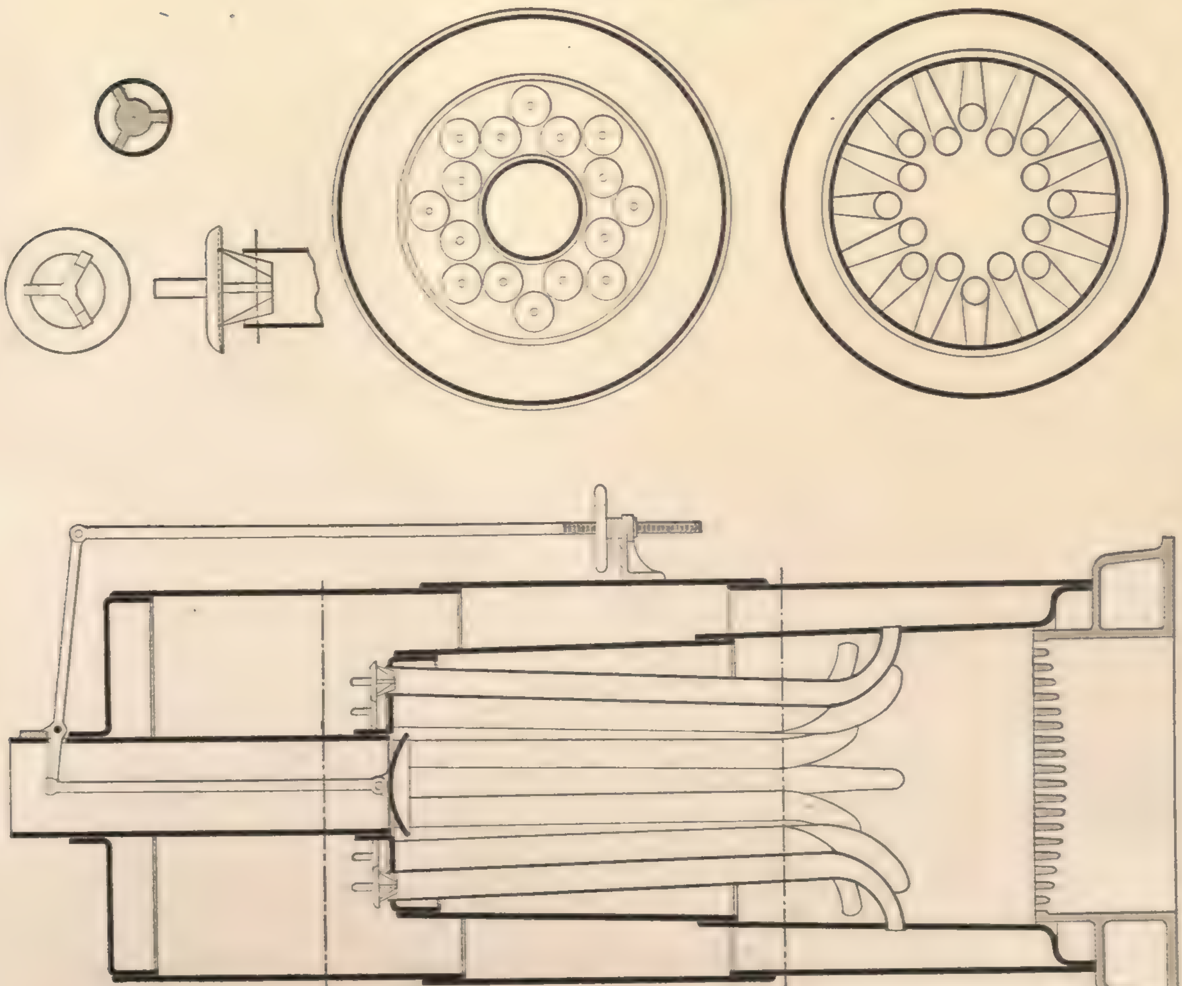


Fig.2.

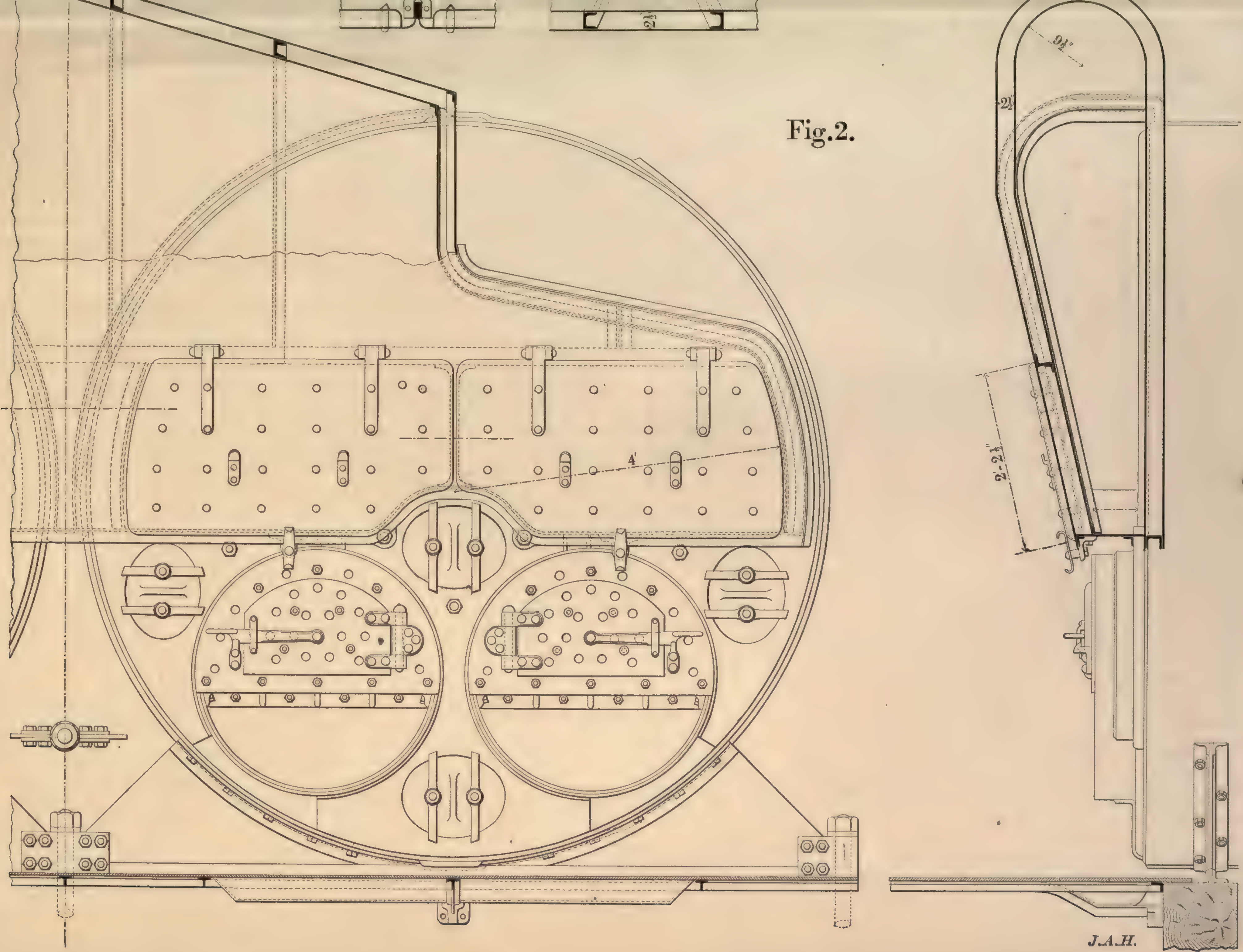


Plate XXIX.

UPTAKE & FURNACE DOORS FOR BOILERS OF U. S. S. "NIPSIC."

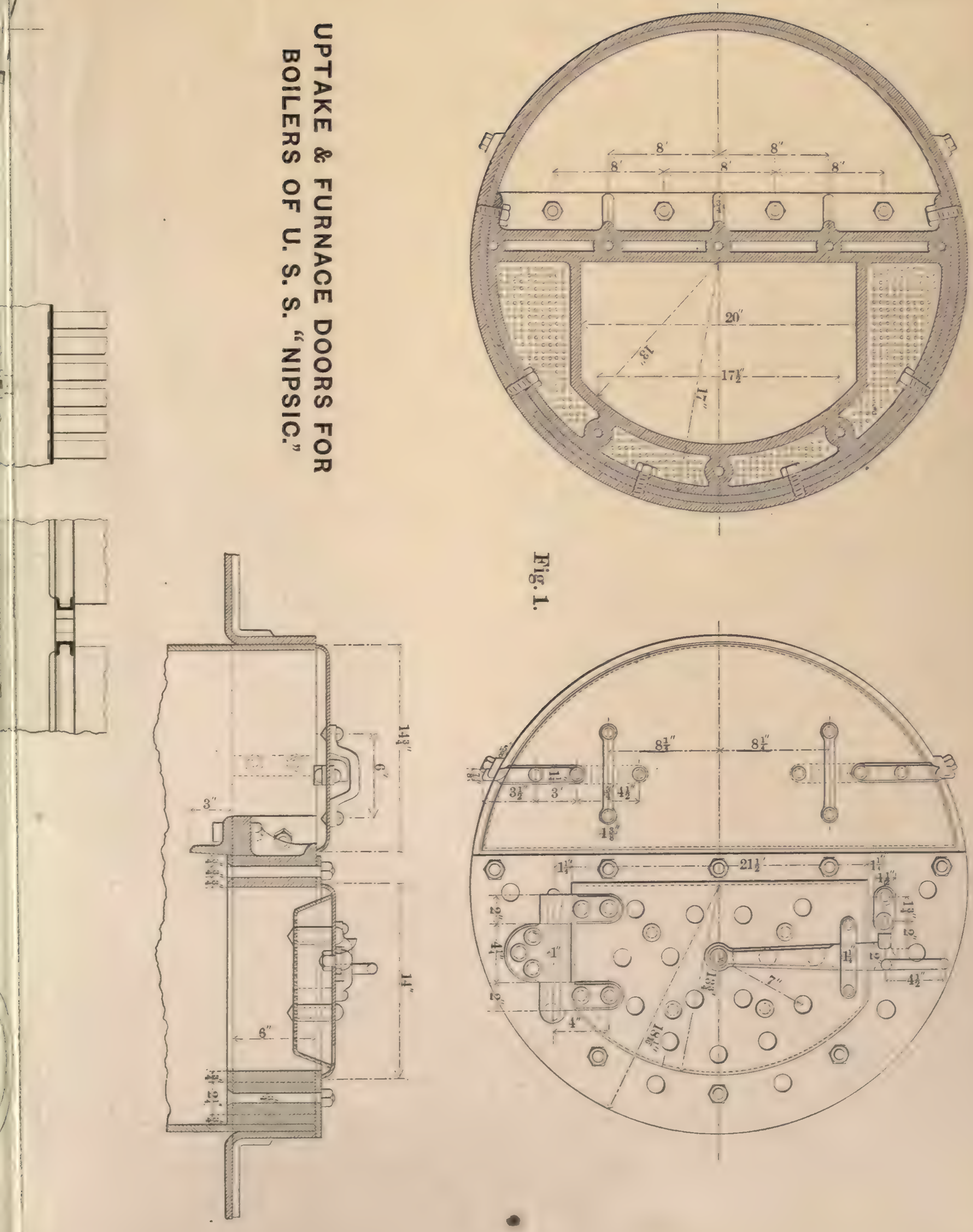


Fig. 1.

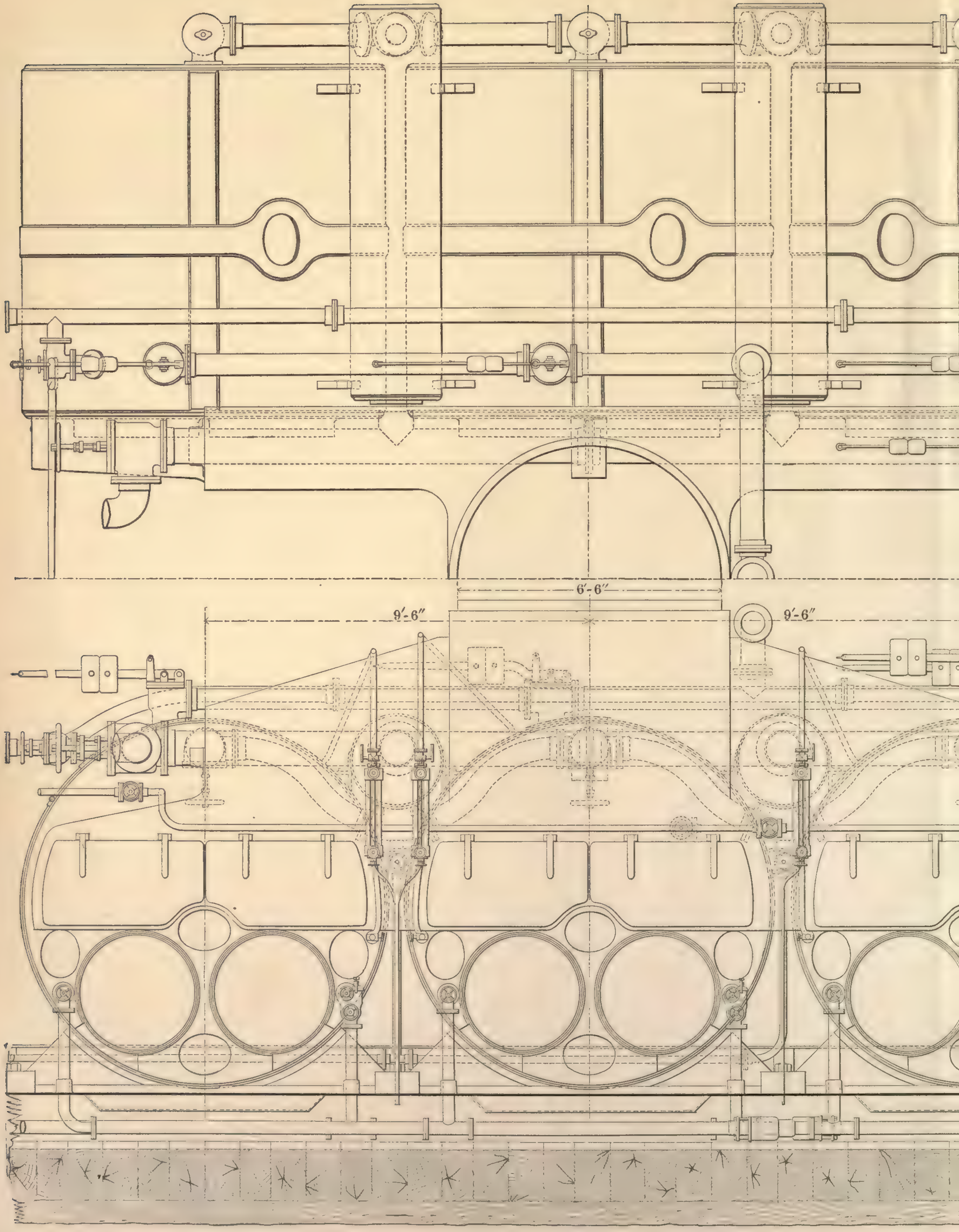
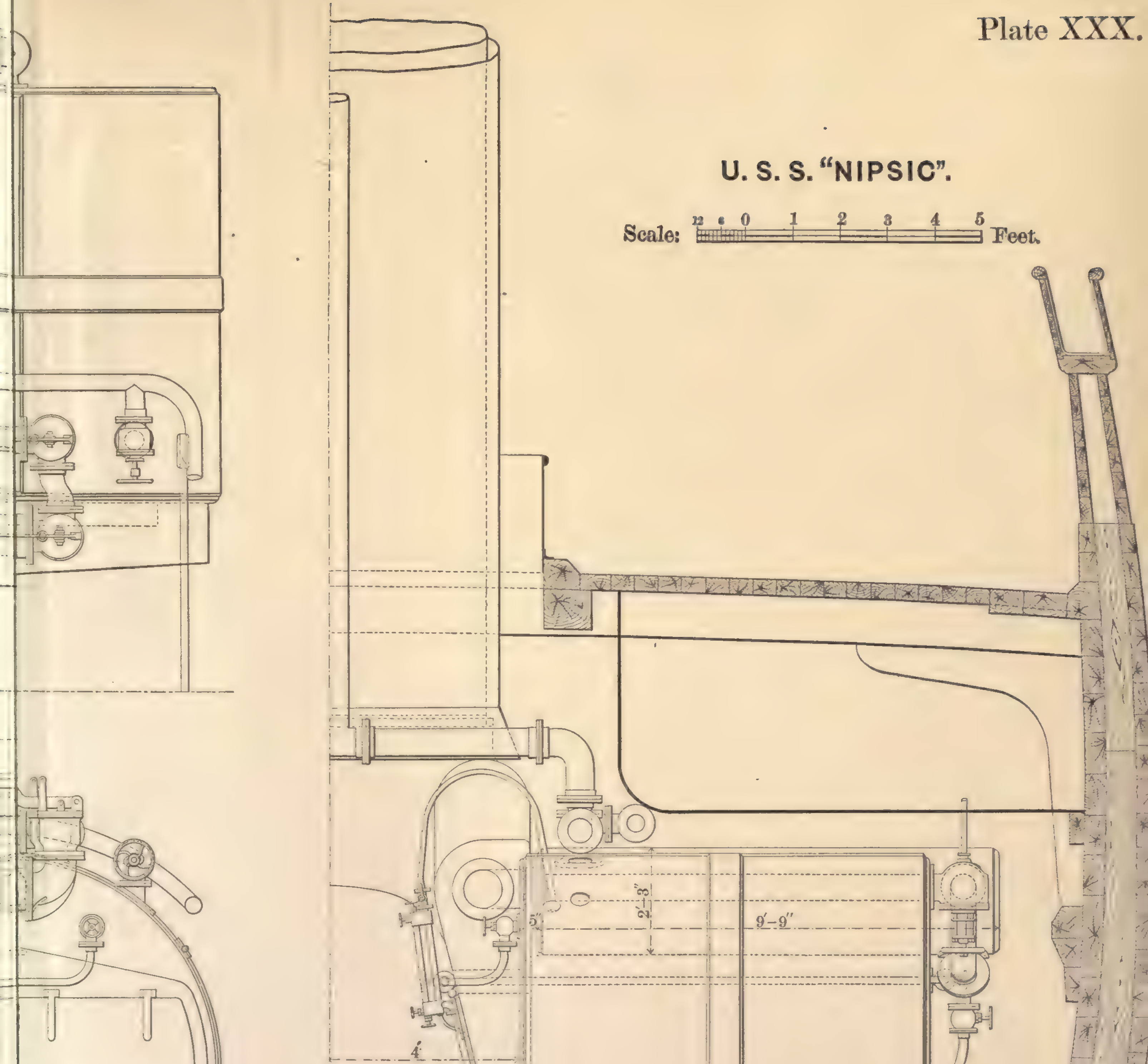

6′-6″
9′-6″
9′-6″

Plate XXX.

U. S. S. "NIPSIC".

Scale: 12 6 0 1 2 3 4 5 Feet.



J.A.H.

Plate XXXI.

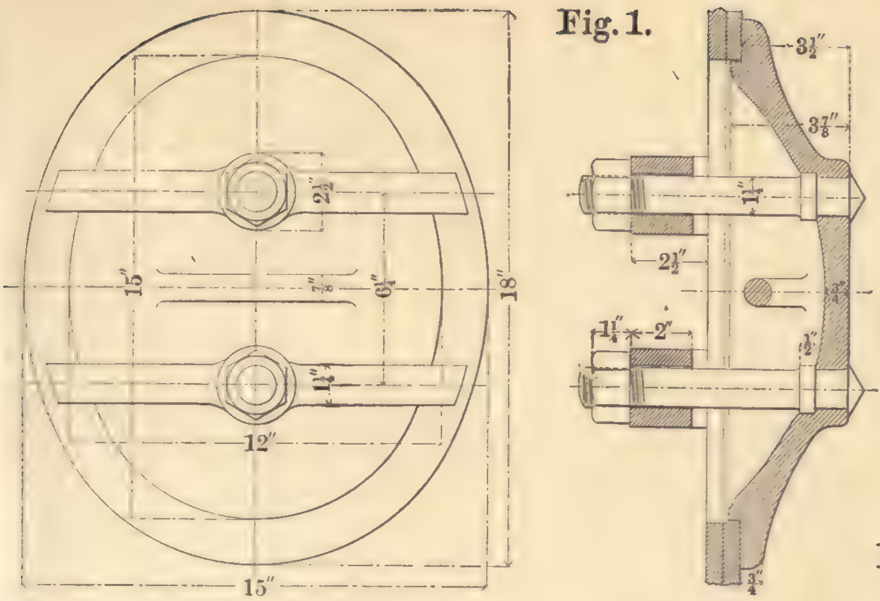


Fig. 1.

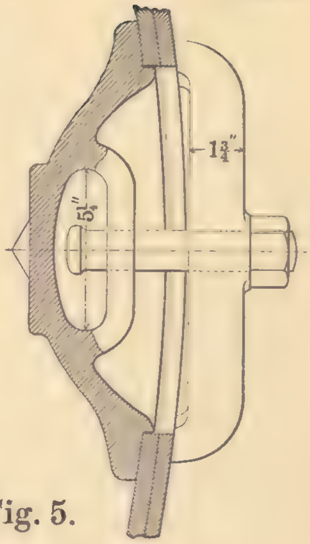


Fig. 5.

Fig. 2.

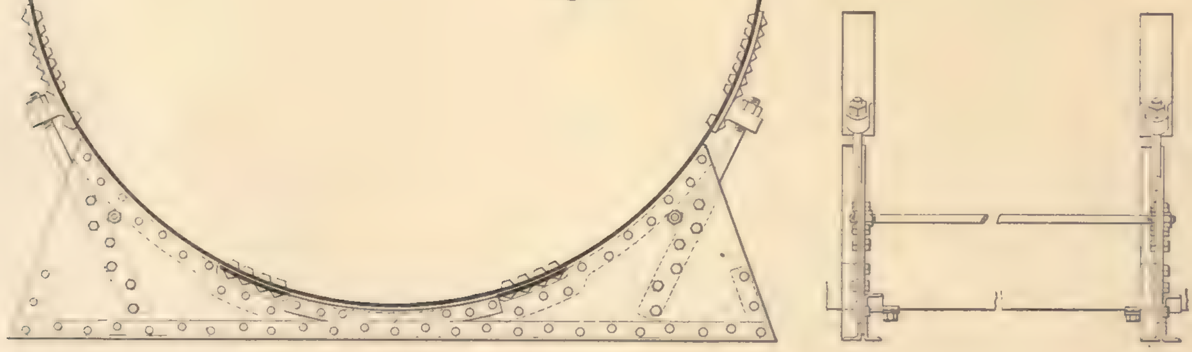


Fig. 3.

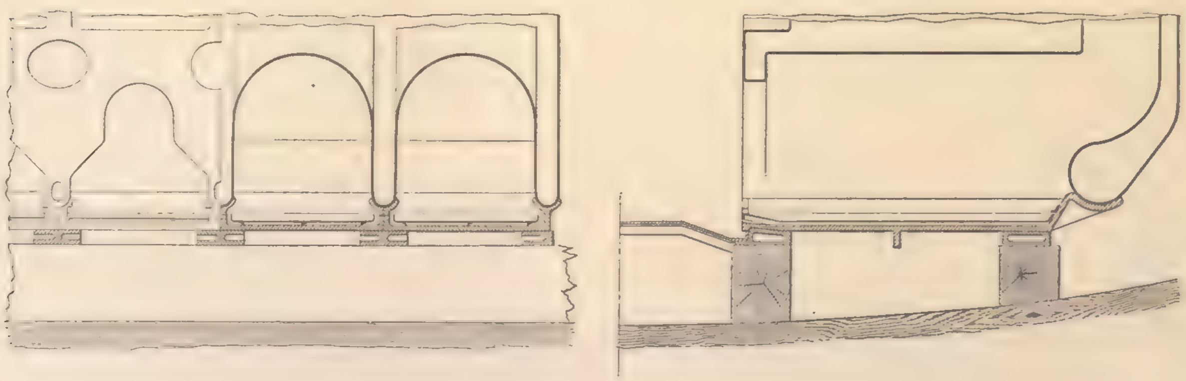
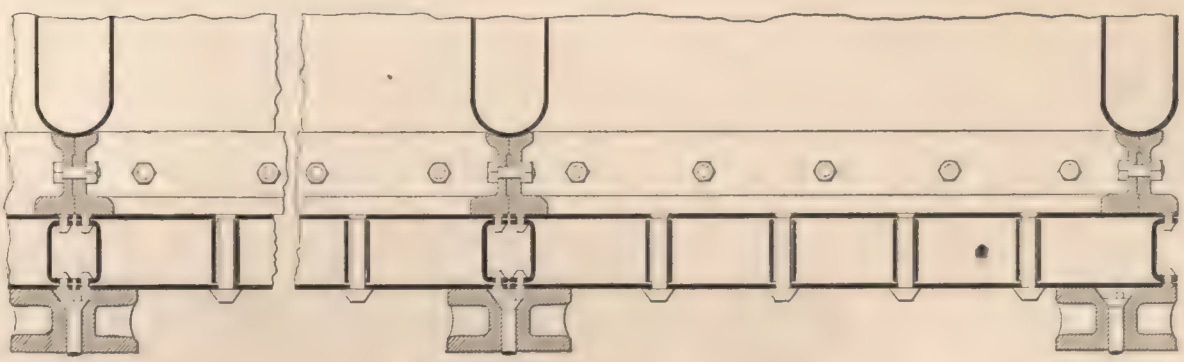


Fig. 4.



STEAM STOP VALVES & FEED VALVE, FOR BOILERS OF U. S. S. "NIPSIC."

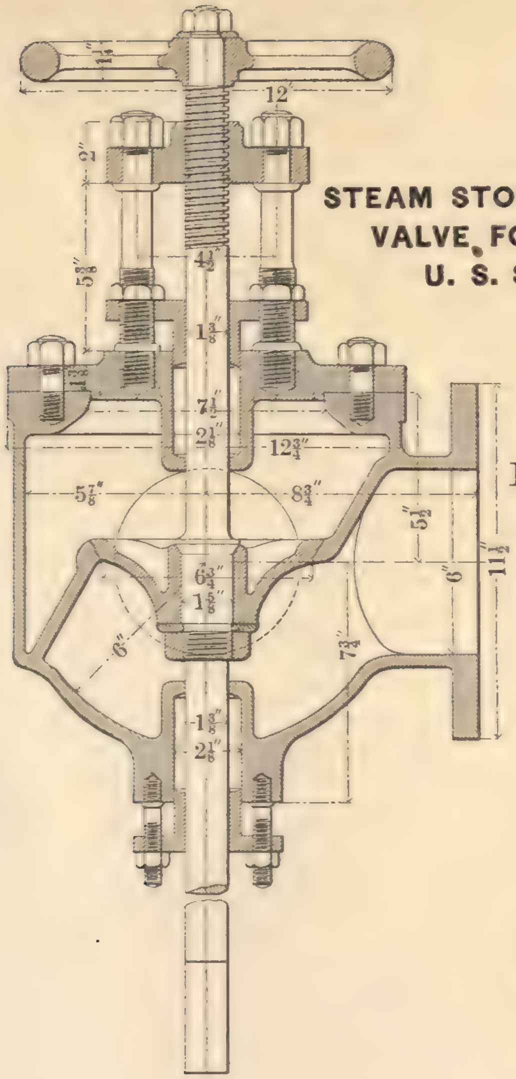


Fig. 1.

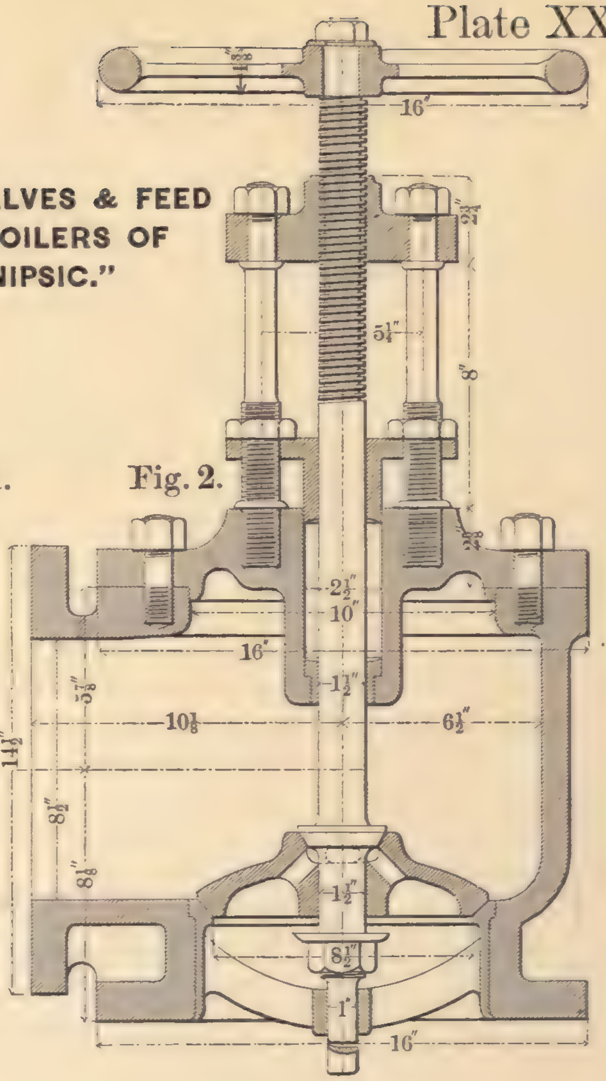
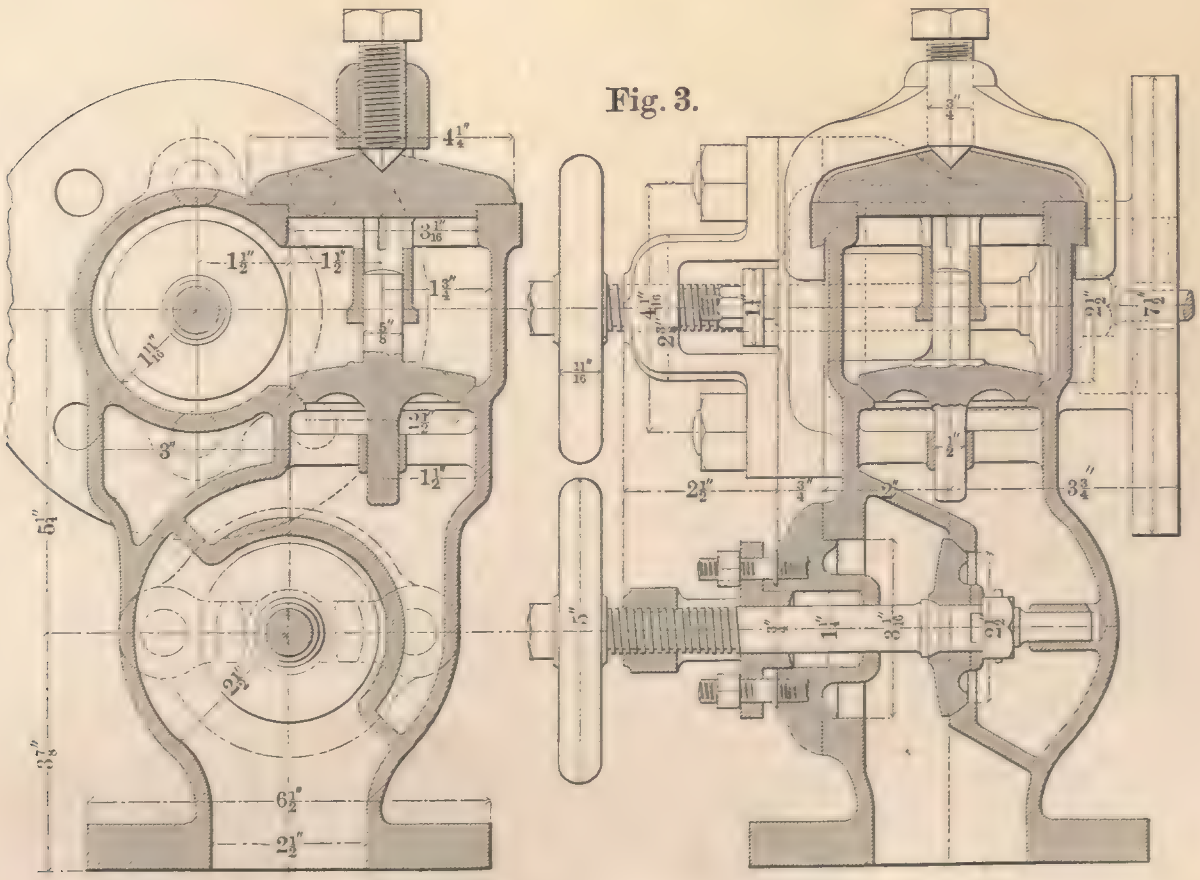
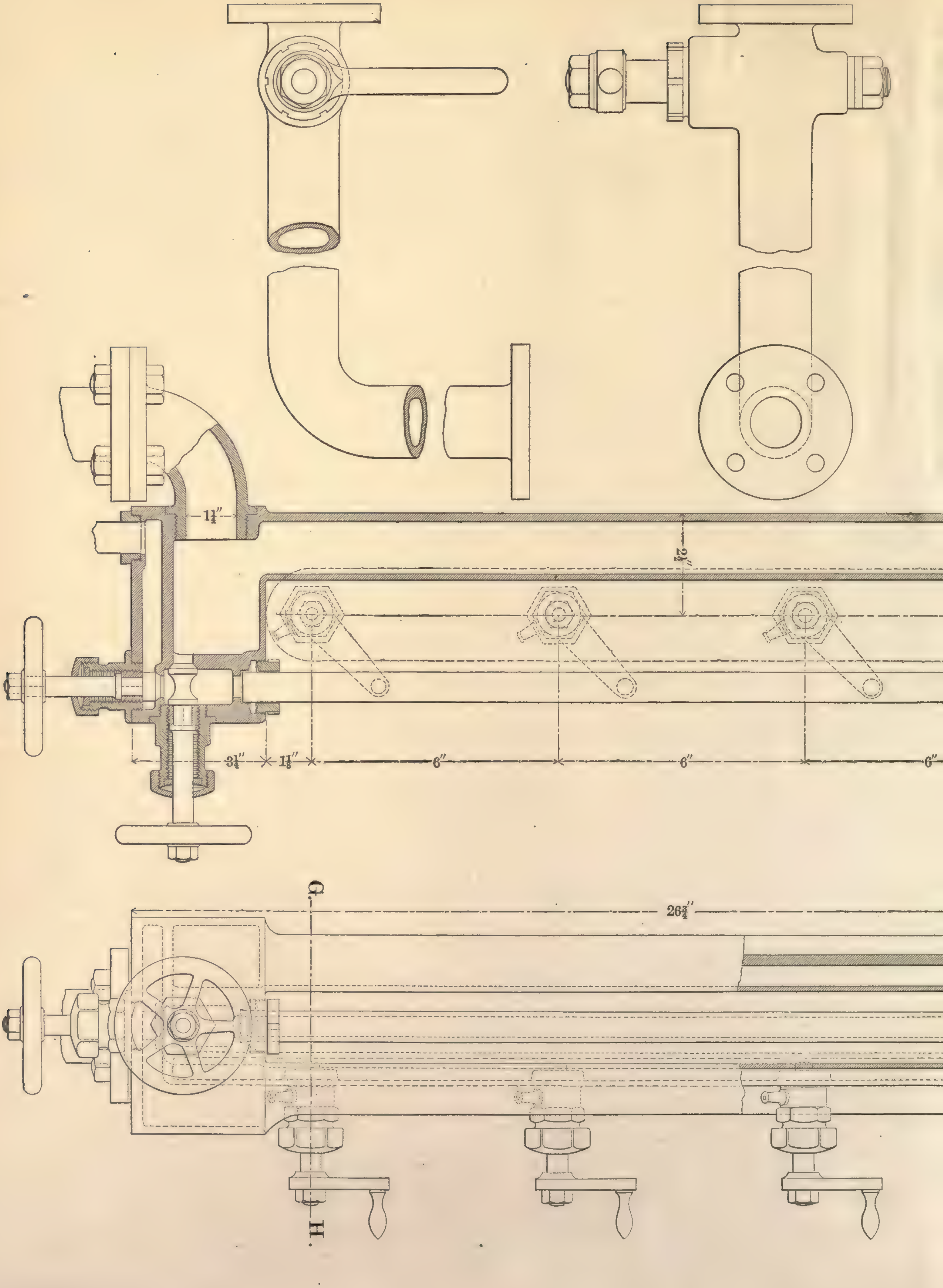


Fig. 2.

Fig. 3.





1¼″
2½″
3¼″
1⅛″
6″
6″
6″
G.
26¾″
H.

Plate XXXIII.

WATER GAUGE FOR BOILERS OF U. S. S. "NIPSIC".

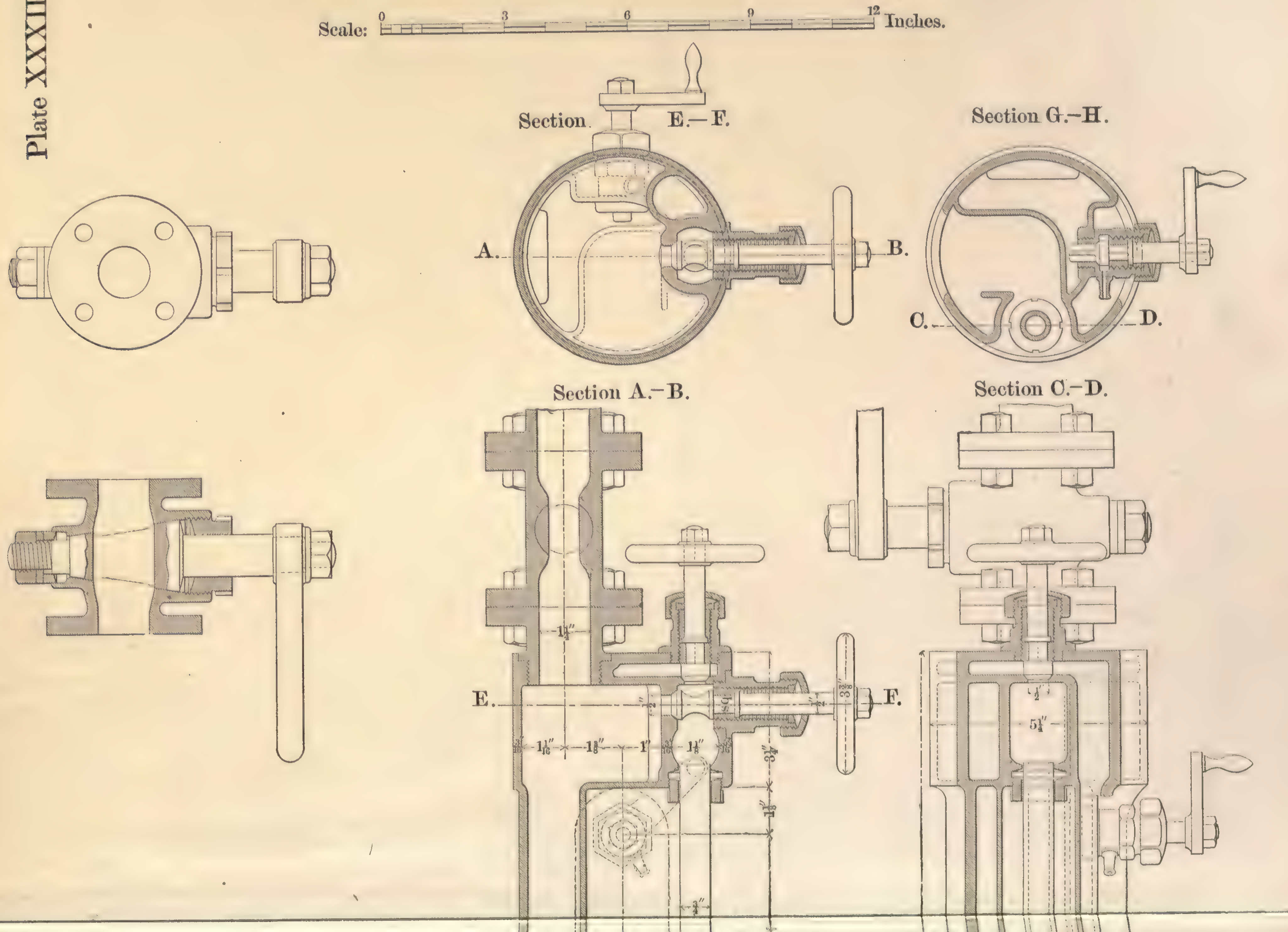


Plate XXXIV.

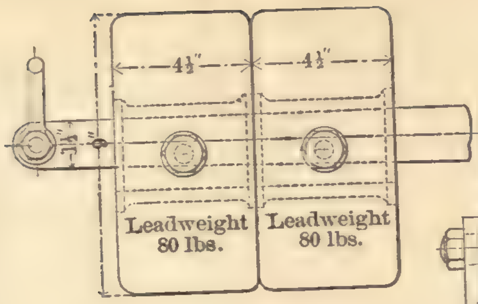


Fig. 1.
SAFETY VALVE FOR BOILERS,
U. S. S. "NIPSIC."

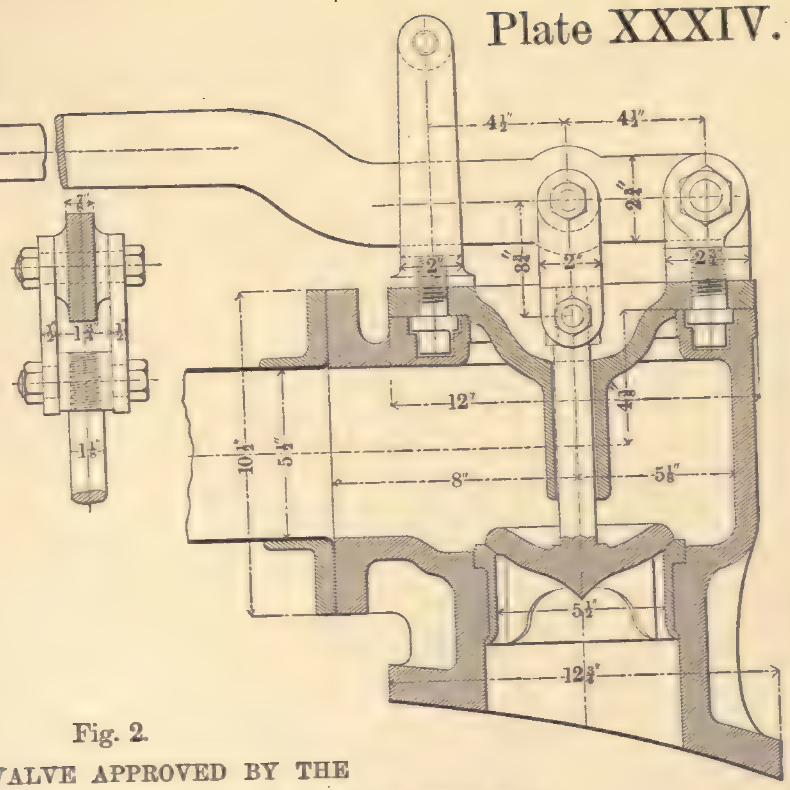


Fig. 2.
SAFETY VALVE APPROVED BY THE
BOARD OF SUPERVISING INSPECTORS OF STEAM-VESSELS.

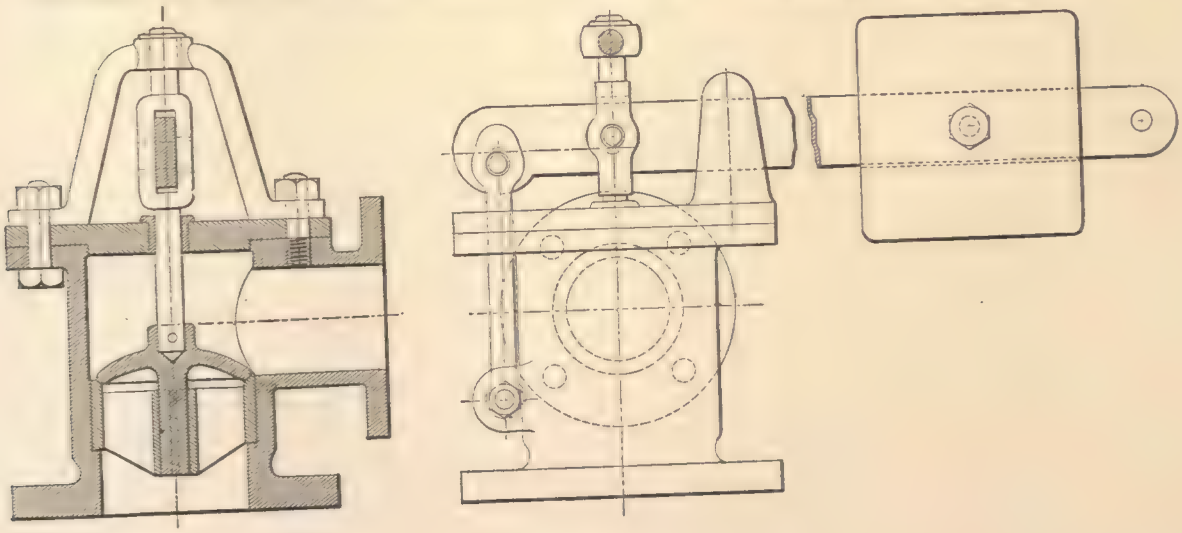


Fig.3.
ASHCROFT'S SAFETY VALVE.

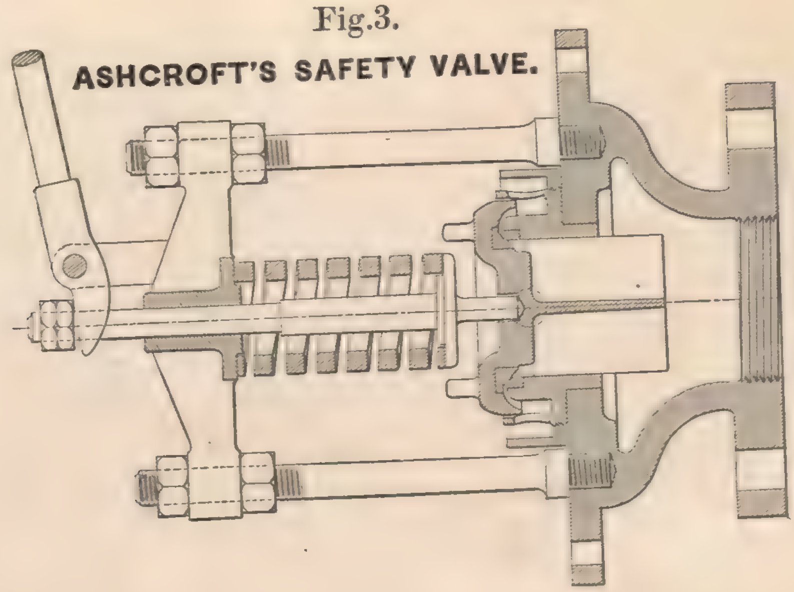


Plate XXXV.

Fig. 1.

KOERTING'S JET APPARATUS.

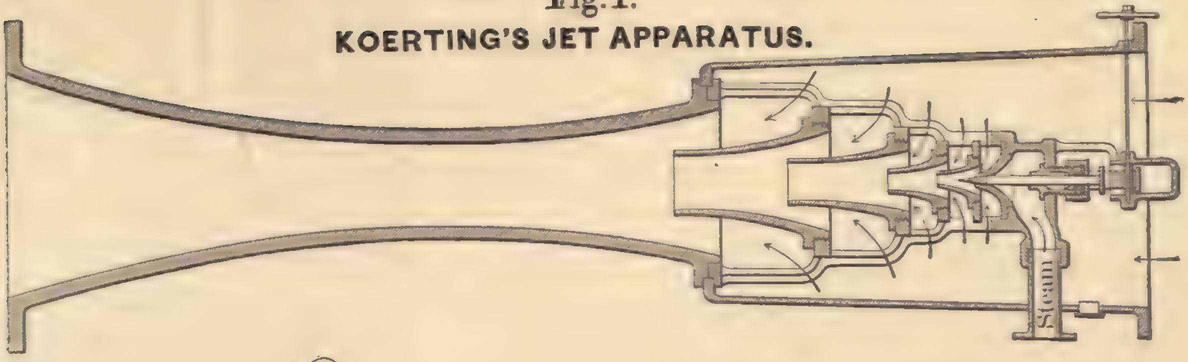


Fig. 2.

SELLERS' SELF-ADJUSTING INJECTOR.

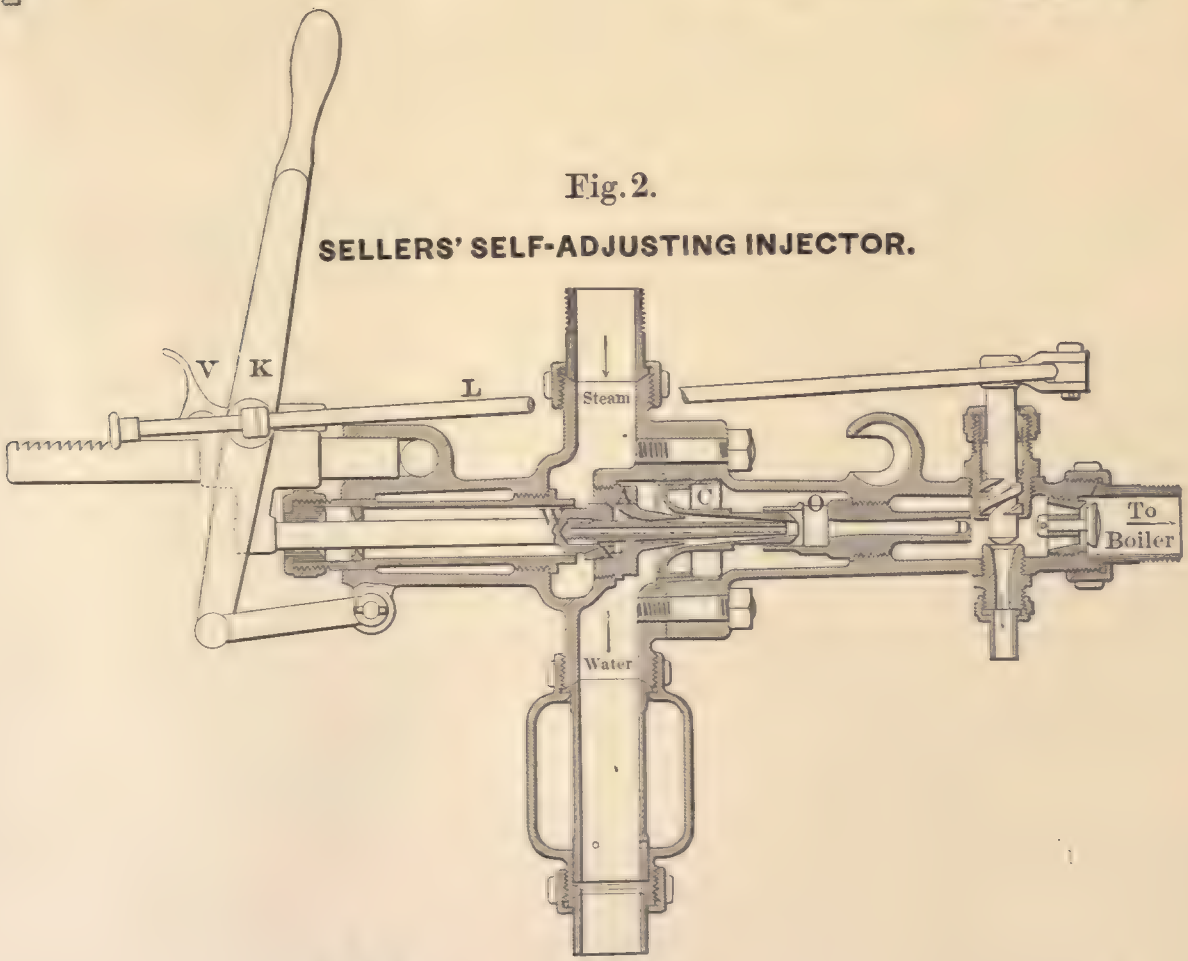


Fig. 3.

KOERTING'S UNIVERSAL LIFTING INJECTOR.

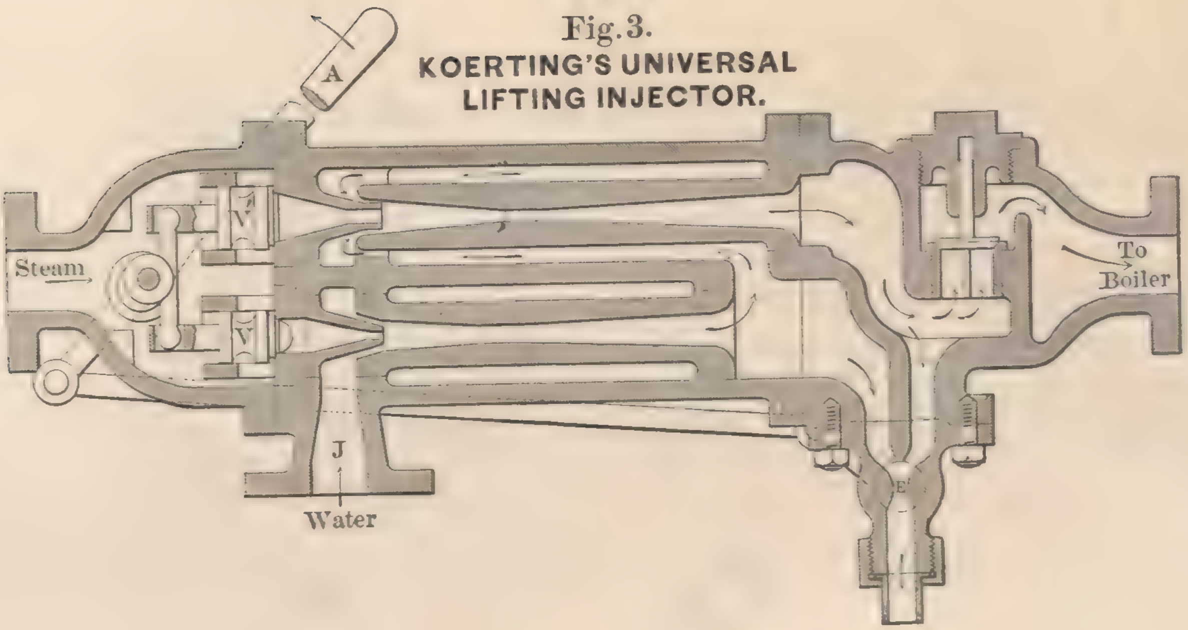


Plate XXXVI.

SPECIMENS OF RIVETS AND RIVET-HEADS

FROM BOILERS OF COPPER-ROLLING MILL,

NAVY YARD, WASHINGTON, D. C. 1879.